The Ecological Effects of Bed Re-levelling on the Wairio Stream

Technical Report

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James Dare
Marine and Freshwater Scientist
Environment Southland

Richard Allibone
Director and Principal Ecologist
Water Ways Consulting Limited

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Table of Contents

Cover Image: *A sediment plume, originating from mechanical disturbance on the Wairio Stream, meets un-affected water from the Otautau Stream.*

List of Figures

List of Tables

1. Executive Summary

In November 2013, Environment Southland undertook a project to lower the bed of Wairio Stream in western Southland, following complaints from local landowners about impeded drainage. A pre-maintenance inspection revealed that the stream bed had aggraded as much as 1.5m above the 1959 survey level, and many tile drain outlets from adjacent farmland were backing up as a consequence. Environment Southland proposed to re-level the stream to the 1959 survey height by mechanically excavating areas of significant gravel accretion.

The Southland Fish and Game office raised concerns over the ecological impact of the proposed re-levelling project, which prompted Environment Southland to carry out a before after control impact (BACI) study to determine if this concern was warranted. The study consisted of three control sites located on the upper Wairio and North Head Streams, and three treatment sites located on the lower Wairio. Electric fishing and fyke netting reaches were established at each site and fished prior to the re-levelling work, and approximately one month after the work had been completed. In addition to fish surveys, trout habitat quality was assessed at each electric fishing and fyke net site using the Trout Habitat Quality Index (THQI). This index has been developed to assess the quality and abundance of adult brown trout habitat (Holmes et al., 2012). However, initial survey results found that juvenile brown trout dominated the trout catch, which led to the development of a juvenile brown trout THQI using information from Jowett et al. (2006). This enabled assessment of juvenile brown trout habitat in relation to the stream bed re-levelling.

Analysis of the fish survey data found that there was no significant treatment-period interaction at the electric fishing reaches, indicating that control and treatment sites underwent similar population changes. However, fyke net surveys revealed a significant decline in: overall fish abundance, the number of brown trout, and the number of longfin eels. Length data also indicated that large brown trout may have dispersed away from the re-levelling reaches in the time between the two surveys. Growth rates of juvenile brown trout were not significantly different at any site during the assessment period, indicating that juvenile fish at control and treatment sites continue to feed and grow at normal rates.

The THQI declined significantly for adult brown trout at electric fishing reaches. Analysis of the habitat data indicated that the decline was predominantly due to an increase in the area of shallow water, which is recognised as being unsuitable for large brown trout. Shallow areas also increased at two of the three treatment fyke net sites, where mechanical re-levelling removed deeper pool and run habitat and created long shallow, homogenous, runs. The juvenile THQI, modified from other indices for the purpose of this study, showed no significant change had occurred post re-levelling, although the range of values at treatment sites had broadened and tended to include a larger number of low scores. The difference between the adult and juvenile THQI result was due to the standard index defaulting to a score of zero for shallow water (0-0.3m), whereas the modified index regarded the same habitat as favourable for juvenile trout and resulted in high scores.

In conclusion, fyke net data showed that large brown trout and long fin eels dispersed away from the treatment reaches following re-levelling, and the THQI work suggested that re-levelling had a substantial impact on the occurrence of adult brown trout habitat. However, the juvenile THQI was not affected due to juvenile brown trout preferring to reside in shallow water habitat, similar to that created by the re-levelling process. Impacts on spawning habitat were uncertain, but spawning in re-levelled reaches is likely to be reduced as fewer large brown trout are supported following the channel works.

For future re-levelling projects, it is recommended that some deep water habitat is created during the works, and that patches of large woody material are added to the channel to provide some habitat diversity. Future studies could also benefit from a more robust sampling design, although this is dependent on available resources.

2. Introduction

Background

Most agricultural practices in Southland are situated on low lying plains that are prone to seasonal flooding. These areas are able to be farmed year-round due to a comprehensive drainage network which has been designed to remove excess water, helping maintain soils in optimal condition for crop growth and grazing (Lalonde & Hughes-Games, 1997; Herzon & Helenius, 2008). Depending on flow dynamics and the local availability of geologic material, these drains are often prone fine sediment and gravel accumulation. If a suitable supply of nutrients and sediment are available, macrophyte growth can establish and dominate an entire drainage reach during the peak growth season. This affects hydraulic performance, which has ongoing implications for the productivity of surrounding farmland (Hudson & Harding, 2004).

Environment Southland manages this problem by regularly maintaining approximately 90 community drainage systems within the Southland region (Hudson & Harding, 2004), while a further 800 drains are estimated to be maintained by private land owners (Hudson & Harding, 2004). Drainage maintenance falls into three broad categories: chemical control, biological control, and mechanical maintenance (Hudson & Harding, 2004). Chemical and biological controls use either chemicals (e.g., glyphosphate) or animals (e.g., sheep) to control channel-clogging macrophyte growth. These methods are highly effective, but they do not remove sediment or gravel deposits, which require the use of heavy machinery. Mechanical drainage maintenance using a hydraulic excavator (digger) is the most common form of maintenance employed by Environment Southland. Excavation contractors start downstream and proceed upstream along the side of the drain, clearing any obstructions they encounter with either a weed rake or bucket scoop. Sediment and weeds are removed from the system and placed in large spoil piles on the side of the banks.

Agricultural drains are internationally recognized as providing habitat for fish, invertebrates, amphibians, and bird life (Gibbs, 2007; Herzon & Helenius, 2008; Hudson & Harding, 2004). Many migratory freshwater fish species in New Zealand are known to migrate through, or use farm drains as habitat or for spawning (Hudson and Harding, 2004). Weed, boulders, and logs which provide important areas of shelter for these species are deliberately targeted and removed from the system, reducing habitat availability, complexity and the carrying capacity for a given reach (Olsen, 2012). Shade-providing vegetation on the sides of the stream bank may also be removed to provide access for excavators, which leads to increased water temperatures, rapid macrophyte growth, and lower levels of dissolved oxygen (Gibbs 2007). Fish may also experience direct mortality by being excavated along with in-stream material and deposited in the piles on the stream bank (Ballantine & Hughes, 2012; Olsen, 2012).

Figure 1: Typical mechanical clearance in Southland.

Sediment re-suspension is another problem associated with mechanical drainage maintenance. This has a number of ecological impacts on downstream communities including: the clogging of gill filaments in fish (Hill, 1997), reduction of light penetration resulting in reduced primary productivity (Hughes & Elliott, 2014), and infilling of interstitial spaces which reduces habitat for macroinvertebrates and bottom dwelling fish (Brookes, 1994; Hudson & Harding, 2004). Re-suspension can also affect local nutrient dynamics by releasing sediment-bound nutrients, such as phosphorus, and affecting localised denitirification potential through removal of organic material (Ballantine & Hughes, 2012).

Drainage maintenance practices have the potential to cause conflict between drainage engineers, who might focus on the hydraulics of drainage networks, and environmental managers who support minimal disturbance to streams and drains to protect their ecological functions (Hudson & Harding, 2004). Regional councils are aware of this, and try to mitigate this conflict by adhering to regionally-specific 'best practice' guidelines. These generally include: avoiding maintenance during spawning seasons or periods of migration (Gibbs, 2007; Hudson & Harding, 2004; Hudson, 2005), placing a sediment trap downstream to prevent excess sediment suspension (Ballantine & Hughes, 2012), ensuring cleaning piles are situated far enough back to prevent collapse into the waterway but close enough to provide stranded fish with an opportunity to return to the stream, and taking all reasonable steps to return dislodged aquatic animals back to the water.

Wairio Stream

The Wairio Stream is a fourth order, hard bottomed stream that feeds the Otautau Stream, north-west of the Otautau township in Southland. In September 2013, Environment Southland's catchment division proposed to use mechanical excavators to remove excess gravel deposits, following concerns from a local land owner that his farm's tile drain network was being compromised by accumulated material. A brief survey revealed that the gravel bed had accreted by a vertical distance of between 0.7 and 1.5m since the stream was reconstructed for drainage purposes in 1959. The proposed drainage maintenance work was justified under rule 46 of the regional water plan, and intended to return the stream bed back to the 1959 level. However, rule 46 requires adherence to the Conservation Act 1987 which states:

> *"it is an offence to disturb or damage the spawning ground of any freshwater fish, or to disturb or injure the eggs or larvae of any freshwater fish"*

This clause prompted the Southland Fish and Game office to oppose the maintenance work, suggesting that the Wairio Stream exhibited: '*loose gravels and minimal fine sediment deposits that were favourable for brown trout (Salmo trutta) spawning*'.

Rule 46 a (iii) also identifies that:

> *"any incidental bed disturbance and removal of gravel shall only be to the extent that it is necessary to undertake the activity and shall be kept to the absolute minimum"*

Fish & Game submitted in support of the inclusion of this condition in the Regional Water Plan, because there have been local examples of gravel excavation exceeding in-stream replenishment, which has resulted in reduced trout spawning and ecosystem values (Z Moss, pers. comm. 2013). They expressed similar concerns over the capacity for the Wairio stream to replenish the volume of gravel planned for removal as part of the re-levelling work. Following deliberation between Environment Southland and Fish & Game, agreement was reached to let the maintenance proceed, but to use the situation as an opportunity to assess the ecological impact through scientific study.

The report at hand was conceived from this agreement, and is intended to assess the ecological impact of drainage maintenance on the Wairio Stream in the following ways:

- quantifying the composition of aquatic communities, before and after impact using two different fish survey methods (electric fishing and fyke netting);
- using a trout habitat quality index (THQI) to assess the before and after suitability of affected reaches for trout habitation.

This work is intended to highlight the extent of ecological impacts associated with drainage maintenance, and help improve techniques going forward.

3. Methods

Introduction

The study at hand was designed as a before-after-control-impact study (see Smith, 2002; Underwood, 1992), with the aim of assessing the impact of mechanical maintenance on community composition (species diversity, abundance, length). Habitat surveys were conducted, and stream cross-sections measured, to provide insight into the morphological changes resulting from the re-levelling process, and to support any findings regarding changes to population structures of the aquatic fauna. Initial surveys took place between the 12th and 15th November 2013, and sites were re-assessed during the week of the 20th January 2014. The re-levelling work was conducted between the 13th and 15th November.

Survey Sites

The study took place on Wairio Stream, north-west of Otautau, Southland (Figure 2). Several adjacent streams were investigated to use as controls; however the North Head stream was the most appropriate due to its hard bottom, proximity, and general similarity to the Wairio Stream. Aquatic community surveys were split into six treatment and six control sites which were spread across Wairio and North Head streams (Figure 3). Two different fish sampling methods, electric fishing and fyke netting, were used to ensure that both shallow riffle, and deep pool-run habitat were appropriately sampled.

Figure 2. Location of the study site (Wairio Stream) in Southland, New Zealand.

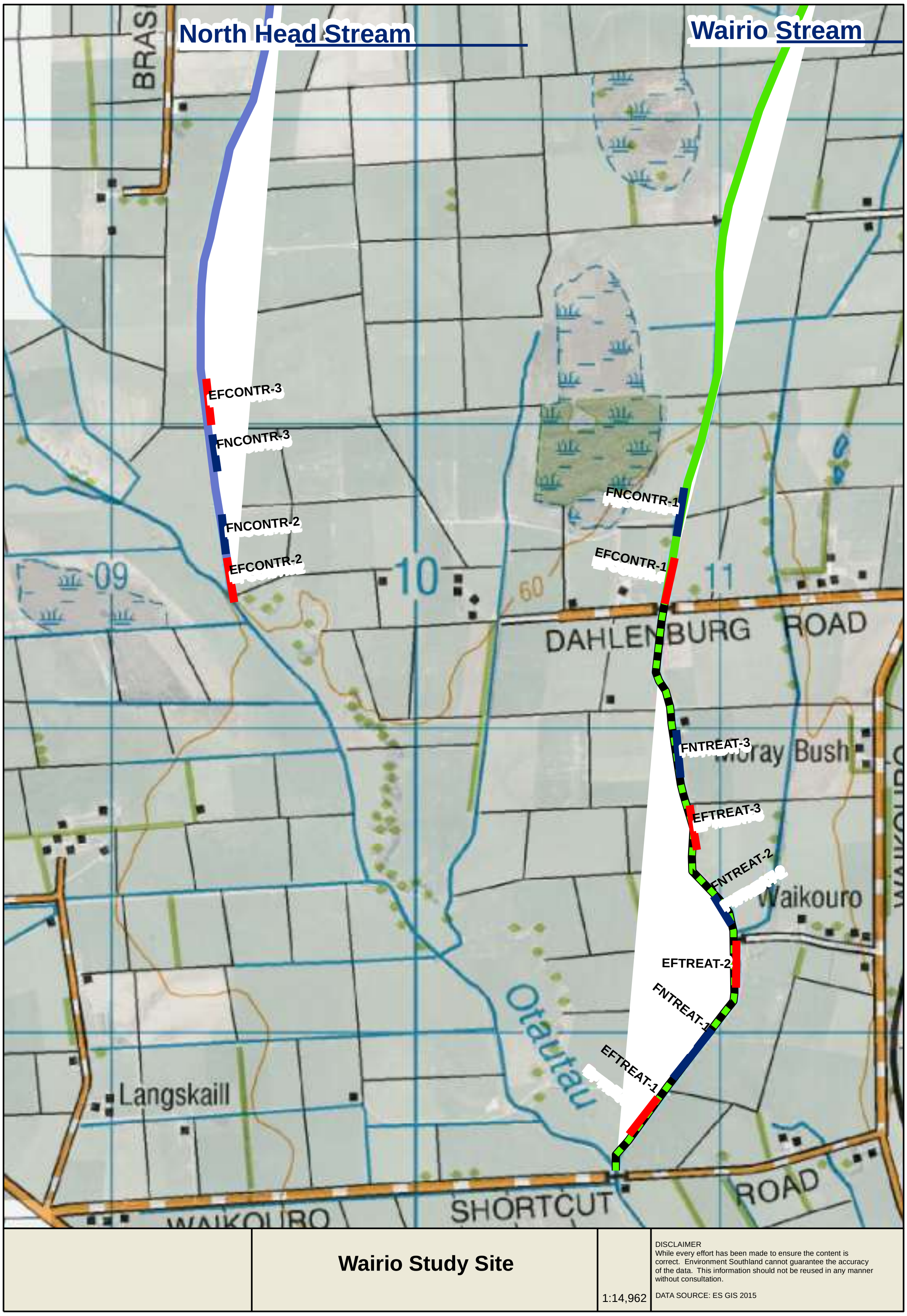

Figure 3. Study sites located on the Wairio (right) and North Head (left) Streams. The stream bed was re-levelled in Wairio Stream between Waikouro Shortcut Road and Dahlenburg Road (denoted by green-black dashed line). Sites are labelled by combining method (Electric Fishing or Fyke Netting), treatment type (TREATment or CONTRol), and the site number (1-3).

Survey Methodology

Electric Fishing

Electric fishing surveys were carried out according to the backpack electrofishing method in the New Zealand Freshwater Fish Sampling Protocols (Joy, David, & Lake, 2013). Each 150 m long electric fishing site was split into ten single-pass 15 m sub-reaches, and sampled with a Kainga EFM300 electric fishing machine. Captured organisms were placed in a holding tank to recover, where they were measured and identified to species level before being released downstream of the current sub-reach. Occasionally the length of large eels had to be estimated due to reluctance to remain stationary. Only the first 30 individuals caught within a single sub-reach and belonging to the same species, were measured.

Fyke Netting

Fyke netting samples were collected using the trapping method outlined in the New Zealand Freshwater Fish Sampling Protocols (Joy et al., 2013). Each 150m long fyke net site was split into six 25 m sub-reaches. One un-baited fyke net, and two un-baited gee minnow traps, were deployed overnight within each sub-reach. Traps were retrieved as early as possible the following morning which resulted in a set time of approximately 18 hours. Individuals were placed in a holding tank before being measured and identified to species level. Occasionally the length of large eels had to be estimated due to reasons stated above.

Trout Habitat Quality Assessment

The quality of habitat within each sub-reach was assessed for its suitability for trout habitation using the trout habitat quality index (THQI) outlined in Holmes et al. (2012). This method required field technicians to make an assessment of the local habitat (Figure 4) according to the following categories: mesohabitat type, depth range, sediment cover type, sediment cover abundance (shuffle test), macrophyte abundance, fish cover, and velocity (see Appendix 1 for an example sheet). Analysis of the scores attributed to each category allowed an average THQI to be calculated for each site. The THQI uses a series of weighting factors to derive scores for the suitability of water depths, fish cover and stream bed substrate for providing habitat for adult brown trout. Fyke net and electric fishing habitat assessments could not be compared directly due to the different number of sub-reaches within each site (10 for electric fishing vs. 6 for fyke netting).

Figure 4. A typical electric fishing reach (top), and fyke netting reach (bottom). Each reach is scored according to the categories that comprise the THQI.

In this study the brown trout population was predominately composed of juvenile individuals less than 100 mm long. Holmes et al. (2012) note in their report that the THQI would benefit from the development of indices for smaller size classes of brown trout, as the adult THQI only represents habitat quality for large brown trout. Therefore, given the abundance of juvenile trout in this survey, the weighting factors for water depth and stream bed substrate where adjusted to provide habitat quality index scores for juveniles as well as adult brown trout. These adjustments were based on habitat preferences for juvenile brown trout (fry to 15 cm long) from Jowett et al. (2006), which in turn was modified from those developed by Raleigh et al. (1986). Water depth and substrate weighting factors for THQI and juvenile THQI are presented in Table 1. No adjustments were made to the weighting factors for fish cover.

Table 1. Weighting for water depth and substrate types for adult and juvenile brown trout for the THQI.

Parameter	Adult brown trout weighting	Juvenile brown trout weighting
Water depth 0 – 0.3 m	0	0.85
Water depth 0.3 – 0.5 m	0.5	0.65
Water depth 0.5 – 1 m	0.8	0.5
Water depth 1+ m	1	0.0
Silt/mud/sand	0.01	0.75
Fine gravel	0.4	0.75
Coarse gravel	0.8	1
Small cobble	0.9	0.6
Coarse cobble	1	0.5
Boulder	1	0.4
Bedrock	1	0.05

Statistical Analysis

Data was analysed using the R statistical language (R Development Core Team, 2011) and generalised linear modelling (GLM) techniques outlined in Zuur et al. (2009). The appropriate model was applied to each dataset according to the distribution of data points. Models were refined using backward-selection, assessed for normality and homogeneity, and then tested against the null hypothesis using an appropriate statistical test. Evidence of an ecological impact was obtained through a statistically significant interaction of treatment and period factors.

4. Results

Electric Fishing Surveys

Total Species Abundance

A total of 1317 individuals were caught during the initial electric fishing survey, compared to 790 in the follow up survey, making 2107 sampled individuals overall. This number was composed of six different species, the most abundant of which was the upland bully (*Gobiomorphus breviceps*) (Table 2). All species, aside from koura (*Paranephrops zealandicus*), and an unidentified species of galaxiid (*Galaxias sp.*), decreased in abundance during the second survey.

Table 2. Composition of species caught during the electrofishing survey. Species are ordered according to total abundance across both survey periods.

Common Name	**Scientific Name**	**Before Count**			**After Count**			**Total Count**
		Control	Treatment	**Total**	Control	Treatment	**Total**	
Upland bully	*Gobiomorphus breviceps*	519	264	**783**	386	119	**505**	1288
Brown trout	*Salmo trutta*	312	81	**393**	92	59	**151**	544
Longfin eel	*Anguilla dieffenbachii*	60	52	**112**	53	30	**83**	195
Koura	*Paranephrops zealandicus.*	9	10	**19**	32	17	**49**	68
Shortfin eel	*Anguilla australis*	2	8	**10**	0	0	**0**	10
Unknown galaxiid	*Galaxias sp.*	0	0	**0**	0	2	**2**	2
Total Collected		**902**	**415**	**1317**	**563**	**227**	**790**	**2107**

Treatment sites one and two experienced slight decreases in the total abundance of individuals caught in the post-impact survey compared with the original survey, while the third treatment site increased very slightly in overall abundance (Figure 5). Fish numbers at all control sites remained relatively constant between sample periods.

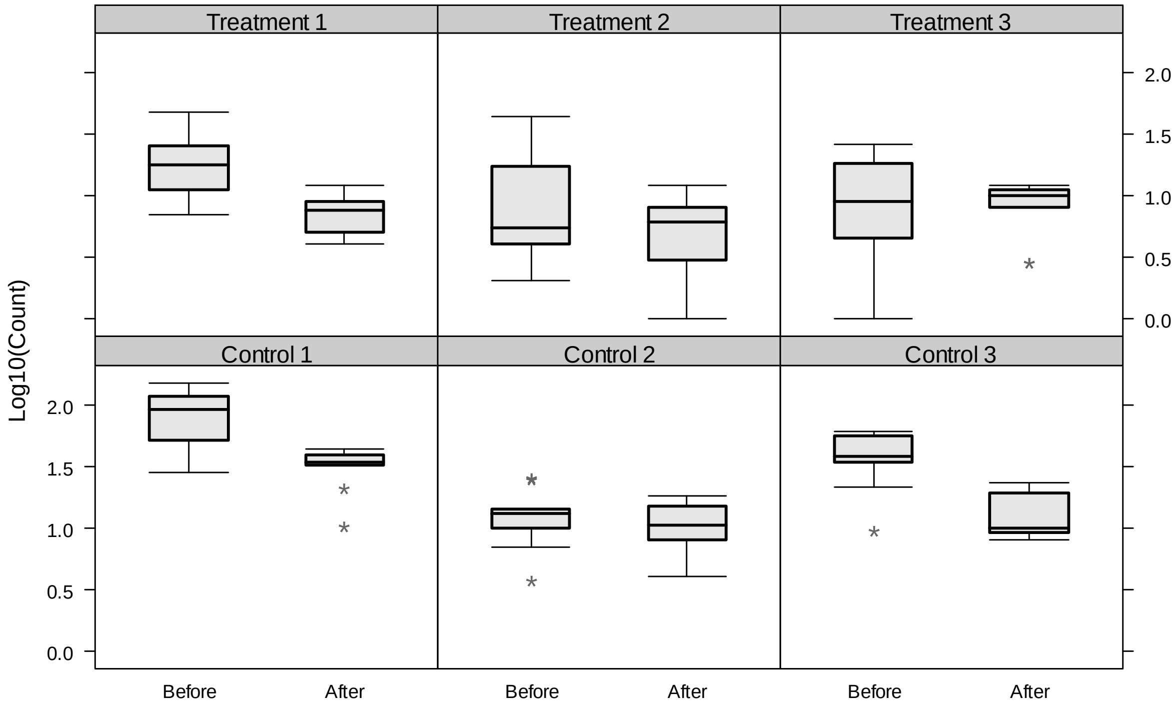

Figure 5. Total abundance of all species caught using the electric fishing method. Box plots have been constructed using 15 m sub-reach data (n = 10), and summarised by study site and timing relative to gravel extraction (before/after). Counts have been log transformed for display purposes.

Statistical analysis of electric fishing abundance data revealed that there was no significant interaction between treatment (control, treatment) and period (before, after) (Dev = 0.39, df=1, p = 0.53), indicating no significant response to drainage maintenance.

Individual species (Electric Fishing)

Brown trout

Brown trout caught at the electric fishing sites before the re-levelling were predominately young of the year (YOY) fish, with a total of 371 brown trout under 63 mm caught. Conversely large brown trout greater than 100 mm were rare with only 22 caught, 15 of which were smaller than 200 mm. The largest brown trout caught was 550 mm from Treatment site 3. The number of brown trout caught from each survey reach differed markedly from 9 to 224 brown trout (Table 3). North Head Stream also appears to support higher numbers of YOY brown trout, as Control Sites 2 and 3 had the highest numbers of small (less than 100 mm) brown trout. These two sites also had the greatest declines in small brown trout in the after survey. Large brown trout were relatively rare and also declined overall between the two surveys (Table 3).

Table 3. The numbers of brown trout caught at electric fishing study reaches.

Stream	Site	Before Count		After Count	
		>100 mm brown trout	< 100 mm brown trout	>100 mm brown trout	< 100 mm brown trout
Wairio	Control 1	4	18	0	24
North Head	Control 2	0	66	0	38
North Head	Control 3	4	220	1	29
Wairio	Treatment 1	7	49	1	29
Wairio	Treatment 2	1	15	3	15
Wairio	Treatment 3	6	3	0	11

Brown trout decreased in abundance at control sites between surveys, but remained relatively constant at treatment sites (Figure 6). The main reason for the decline in the control sites was the reduction in the numbers of brown trout at Control Site 3 to 13% of that in the before survey. Overall this species did not show a significant interaction between treatment and survey period (Dev = 1.53, df=1, p=0.22) suggesting that population changes were independent of drainage maintenance disturbance.

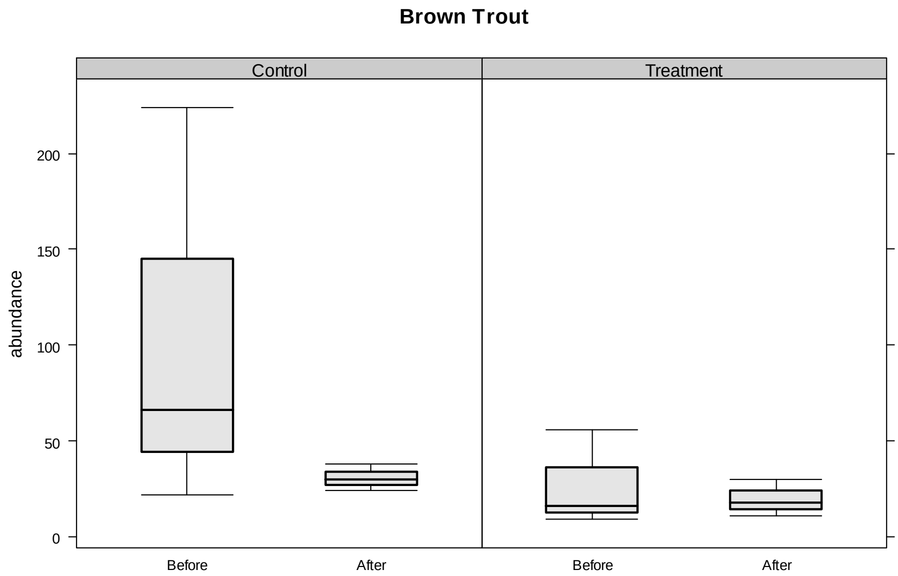

Figure 6. Total abundance of brown trout caught using the electric fishing method. Box plots have been constructed using 15 m sub-reach data (n = 30), and summarised by treatment (control/treatment) and timing relative to gravel extraction (before/after).

Brown trout in both treatment types, were markedly smaller during the initial survey (mean=53 mm) than the follow up survey (mean=86 mm) (Figure 7). Statistical analysis confirmed the effect of period (Dev=6.83, df=1, p<0.001) and site class (Dev=0.39, df=1, p<0.001), but failed to detect a significant period-treatment interaction (Dev=0.06, df=1, p=0.13).

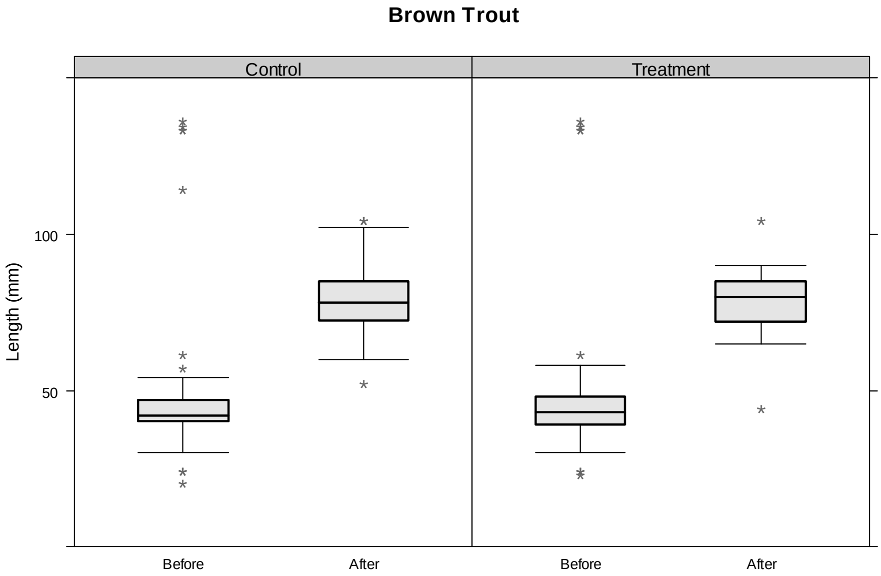

Figure 7. Lengths (mm) of brown trout caught using the electric fishing method. Data has been summarised by treatment (control/treatment) and timing relative to gravel extraction (before/after) (n = 30).

An analysis of the length range of YOY brown trout found that the average length at the six sites ranged between 38 mm and 43.4 mm. A one-way analysis of variance (ANOVA) found no significant difference in the length of the YOY brown trout between sites (df = 5, F=1.567, p=0.168). In the post re-levelling sampling, the length range of YOY brown trout averaged between 75 mm and 81 mm across the six sites. A one-way ANOVA revealed no significant difference in the YOY lengths (df=5, F=0.928, p=0.464). This would indicate that YOY of the brown trout were of similar lengths prior to the re-levelling and continued to grow at the same rate in the treatment and control sites during and after re-levelling.

Koura

Koura were seen to increase in abundance post-impact at the control site, but not at the treatment site (Figure 8). Statistical analysis shows that there was no significant interaction between treatment and period on the abundance of this species (Dev=1.81, df=1, p=0.18).

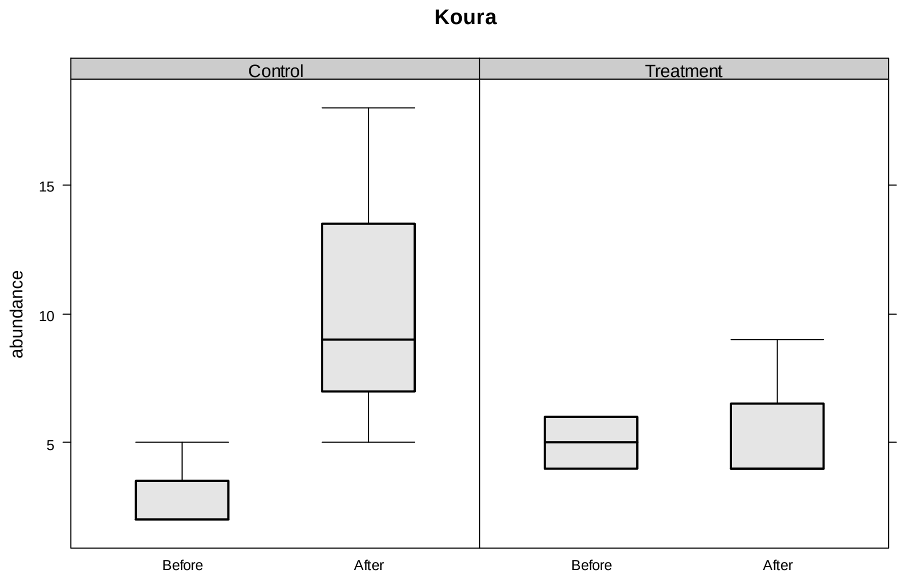

Figure 8. Total abundance of koura caught using the electric fishing method. Box plots have been constructed using 15 m sub-reach data (n = 30), and summarised by treatment (control/treatment) and timing relative to gravel extraction (before/after).

Overall, the average length of koura increased from 42 mm to 64 mm between surveys (Figure 9). This increase was statistically significant (df=1, F=25.67, p<0.001), but there was no evidence of a period-treatment interaction (df=1, F=1.73, p=0.19).

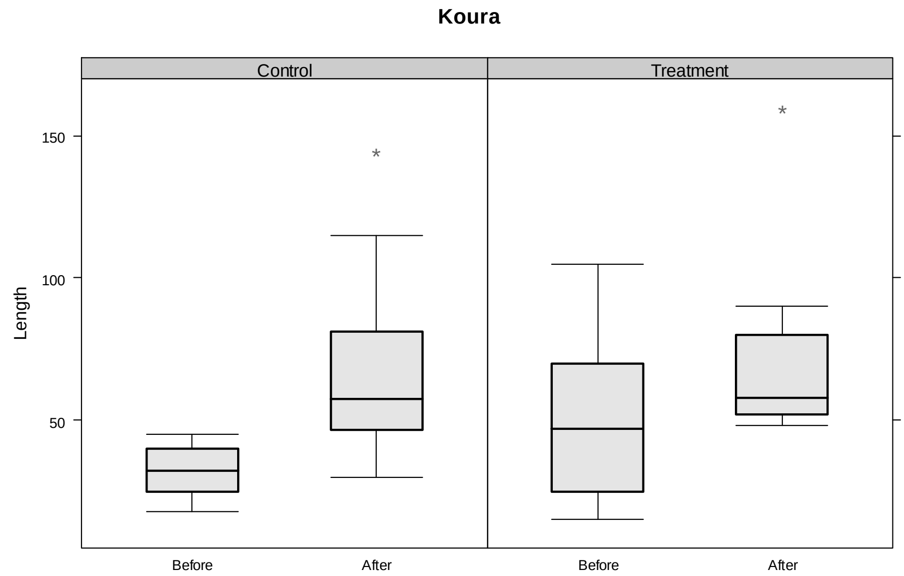

Figure 9. Lengths (mm) of koura caught using the electric fishing method. Data has been summarised by treatment (control/treatment) and timing relative to gravel extraction (before/after) (n = 30).

Longfin Eel

The abundance of longfin eel remained relatively constant within the control site, but decreased post-impact at the treatment site (Figure 10). This response pattern is superficially indicative of an environmental impact; however, this was not statistically validated (Dev=1.04, df=1, p=0.31).

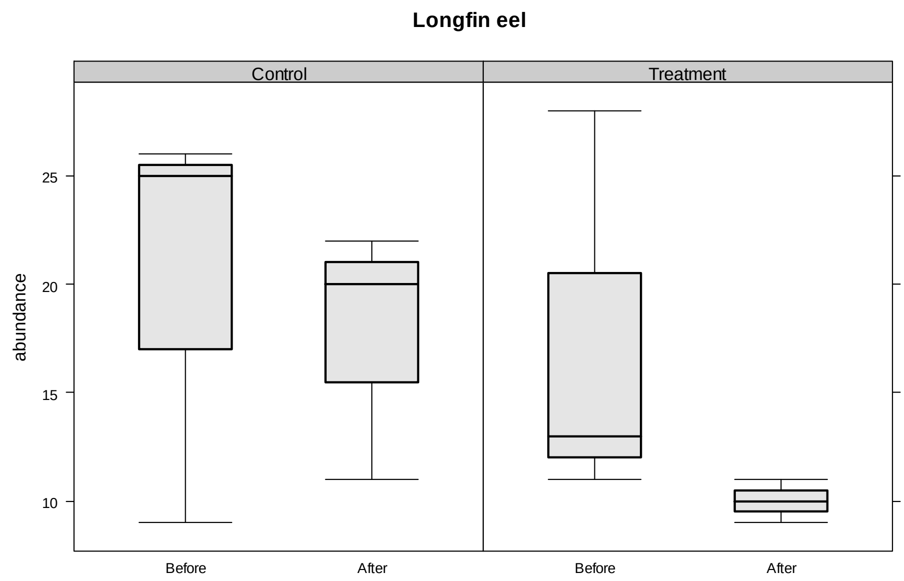

Figure 10. Total abundance of longfin eels caught using the electric fishing method. Box plots have been constructed using 15 m sub-reach data, and summarised by treatment (control/treatment) and timing relative to gravel extraction (before/after).

Longfin eels sampled using the electric fishing technique had a median length of 493 mm at control sites and 355 mm at treatment sites (Figure 11). Lengths were significantly different between treatment type (df = 1, F=27.5, p<0.001) but there was no indication of a treatment-period interaction (df=1, F=3.09, p=0.08).

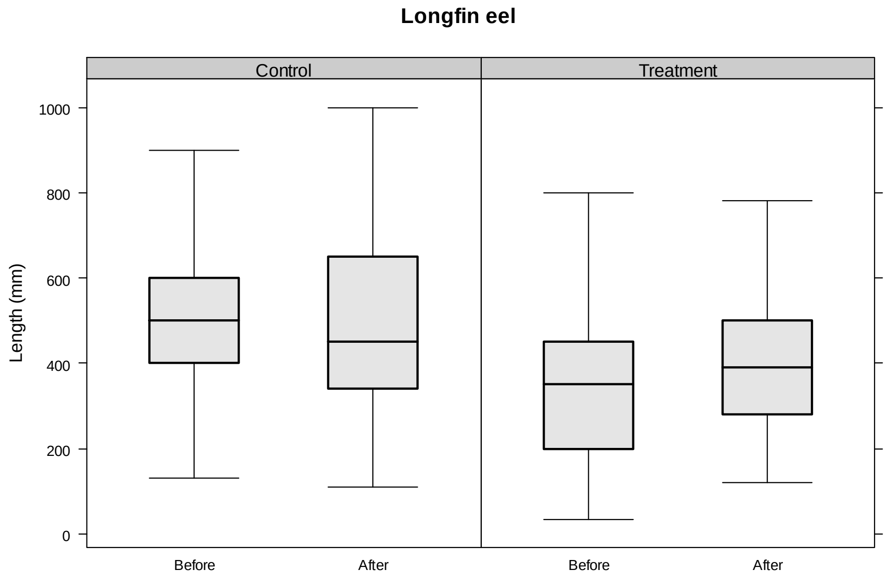

Figure 11. Lengths (mm) of longfin eels caught using the electric fishing method. Data has been summarised by treatment (control/treatment) and timing relative to gravel extraction (before/after).

Upland Bullies

Upland bullies showed a similar pattern to longfin eels (Figure 12), although the abundance of this species in the control reach decreased significantly. This result also failed to reveal evidence of a significant environmental impact (Dev=0.63, df=1, p=0.43).

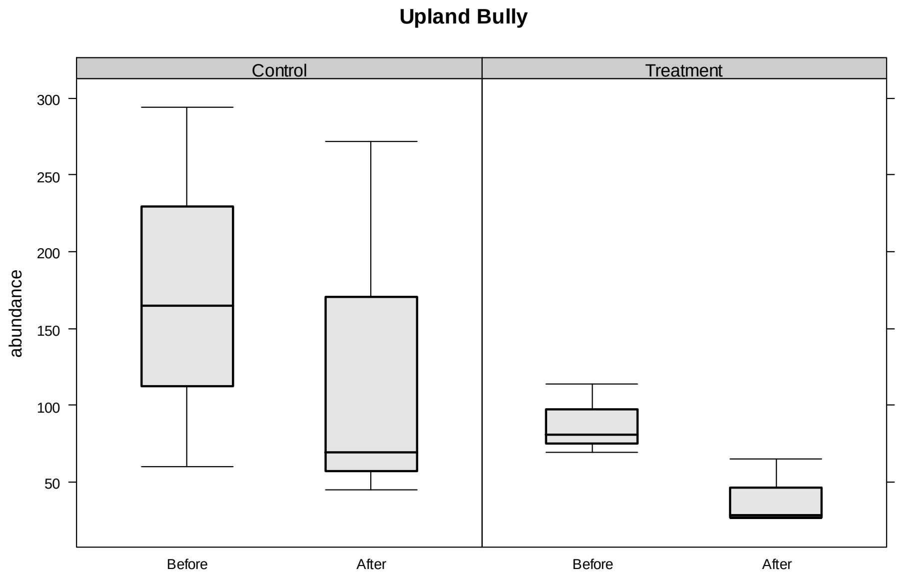

Figure 12. Total abundance of upland bullies caught using the electric fishing method. Data has been summarised according to treatment (control/treatment) and timing relative to gravel extraction (before/after).

Upland bullies had a median length of 40 mm at control sites and 41 mm at treatment sites (Figure 13). Analysis revealed a difference in length between treatment type (df=1, F=37.88, p<0.001) and a significant increase in size between surveys (df=1, F=129.40, $p<0.001$), but failed to show a treatment-period interaction (df=1, F=0.22, p=0.63).

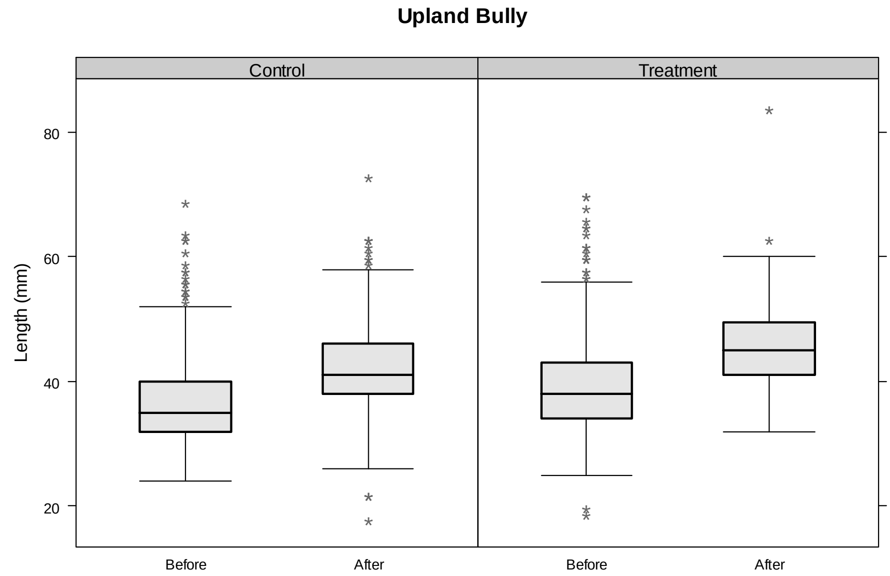

Figure 13. Lengths (mm) of upland bullies caught using the electric fishing method. Data has been summarised by treatment (control/treatment) and timing relative to gravel extraction (before/after).

Fyke Net Surveys

A total of 342 individuals were caught in the fyke-net surveys. This was comprised of 237 individuals in the pre-impact survey, and 105 in the follow-up survey. Six different species composed the total catch (Table 4), the most abundant being upland bully which reduced from 148 to 8 individuals between survey periods. Brown trout also reduced in numbers by seven between sampling periods, while longfin eels and koura increased slightly in the after surveys due to significant increases at the control.

Table 4. Composition of species caught during the fyke-netting survey. Species are ordered according to total abundance across both survey periods.

Common Name	Scientific Name	Before Count			After Count			Total Count
		Control	Treatment	Total	Control	Treatment	Total	
Upland Bully	*Gobiomorphus breviceps*	59	89	**148**	8	0	**8**	156
Longfin Eel	*Anguilla dieffenbachii*	30	26	**56**	49	18	**67**	123
Brown Trout	*Salmo trutta*	11	16	**27**	17	3	**20**	47
Koura	*Paranephrops sp.*	2	2	**4**	4	4	**8**	12
Unknown galaxiid	*Galaxias sp.*	0	0	**0**	1	1	**2**	2
Shortfin Eel	*Anguilla australis*	2	0	**2**	0	0	**0**	2
Total		**104**	**133**	**237**	**79**	**26**	**105**	**342**

In general, the total abundance of all species caught using the fyke net method was seen to decrease at treatment sites and remain relatively constant at control sites (Figure 14). Statistical analysis revealed a significant interaction between treatment and period (Dev=7.72, df=1, $p<0.01$), which suggests that the communities targeted by fyke net sampling were negatively affected by stream re-levelling disturbance. The analysis also found a significant difference in abundance between species (Dev=70.54, df=5, p<0.001), and a species-period interaction (Dev=15.51, df=3, p<0.01). This supports that finding that the different species caught by fyke netting responded differently to the re-levelling.

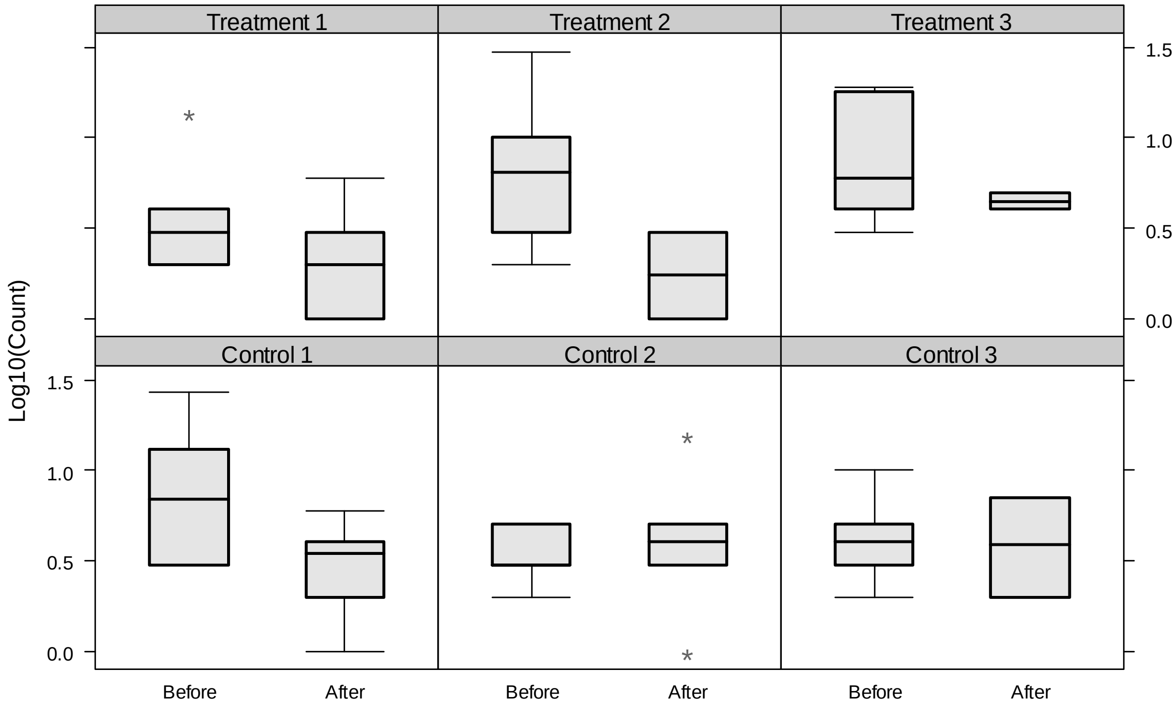

Figure 14. Total abundance of all species caught using fyke nets. Box plots have been constructed using 15m sub-reach data, and summarised by treatment (control/treatment) and timing relative to gravel extraction (before/after).

Individual species

Longfin eels and brown trout were the only species found at each of the six fyke net sites, therefore only these species are represented in the individual abundance plots below.

Longfin eel

Longfin eels increased in abundance at control sites and decreased at treatment sites between pre and post disturbance sampling (Figure 15). Analysis revealed a statistically significant treatment-period interaction (Dev=5.09, df=1, p<0.05), which suggests that the population was negatively affected by drainage maintenance disturbance at treatment sites.

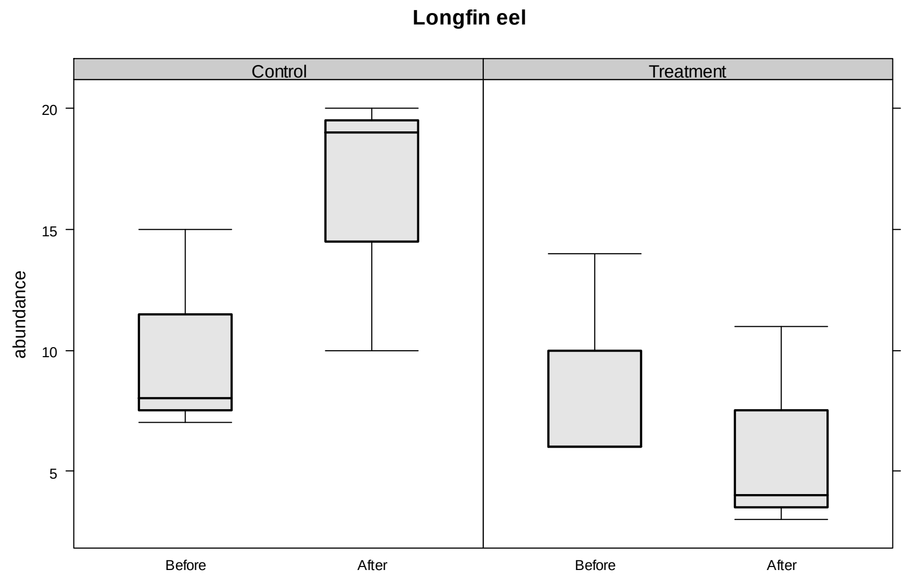

Figure 15. Total abundance of longfin eels caught using fyke nets. Box plots have been constructed using 15 m sub-reach data, and summarised by treatment (control/treatment) and timing relative to gravel extraction (before/after).

Longfin eels sampled using the fyke net method had an average length of 555 mm in treatment sites and 615 mm in control sites (Figure 16). Statistical analysis revealed that length was not influenced by period, treatment, or an interaction between period and treatment (df=1, F=3.76, p=0.055).

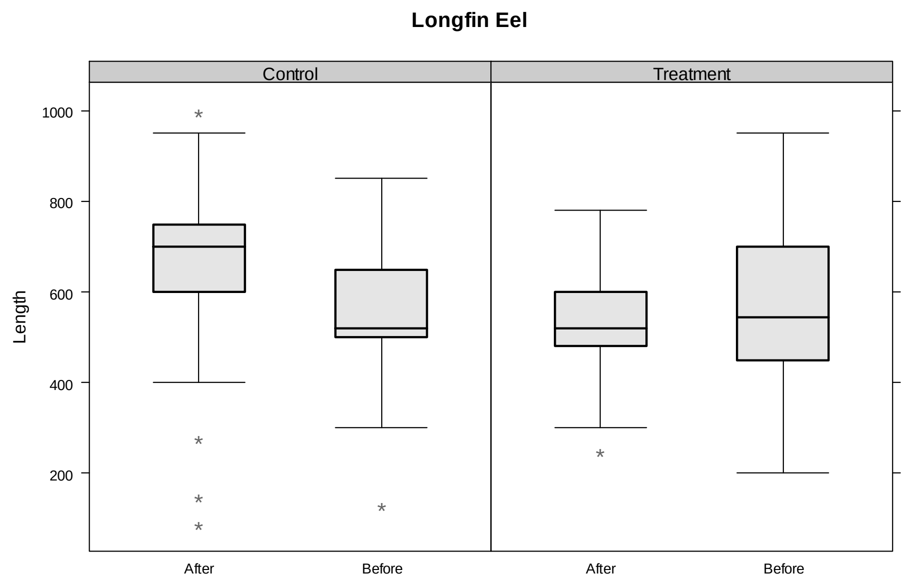

Figure 16. Lengths of longfin eels caught using fyke nets. Data has been summarised by treatment (control/treatment) and timing relative to gravel extraction (before/after).

Brown Trout

Forty seven brown trout where caught in the before re-levelling survey in the fyke net reaches. These ranged in length from 36 mm to 540 mm. A total of eight brown trout were 180 mm or greater in length and the remaining 39 brown trout where between 52 mm and 36 mm long. Unlike the electric fishing reaches, relatively few young of the year brown trout were caught. This may be due to the small brown trout avoiding the nets, escaping, or suffering predation while captured.

The distribution of large brown trout (>100mm) between surveys is of particular interest. Prior to disturbance, the distribution of large trout was centred at Treatment Sites 2 and 3 (3 trout each), and Control Sites 1 and 3 (1 trout each). Following disturbance, the number of large trout at treatment sites reduced to one at each of Treatment Sites 1 and 2, and the number caught at Control Site 1 increased to five (Table 5). The increased catch of large brown trout at Control Site 1 may indicate that large brown trout moved upstream from the re-levelling reaches to the undisturbed control reach. Control Sites 2 and 3 in the North Head Stream did not see the same increase in large brown trout at the fyke net study reaches.

Overall, the abundance of brown trout in the fyke net reaches remained relatively constant at control sites but decreased at treatment sites (Figure 17). This species showed a significant treatment-period interaction (Dev=10.01, df=1, $p<0.01$) which suggests that the catch rate declined in the follow up survey due to disturbance from drainage maintenance.

Table 5. The numbers of brown trout caught at fyke net study reaches.

Stream	**Site**	**Before Count**		**After Count**	
		>100 mm Brown trout	**< 100 mm brown trout**	**>100 mm Brown trout**	**< 100 mm brown trout**
Wairio	Control 1	1	2	5	0
North Head	Control 2	0	3	0	11
North Head	Control 3	1	4	0	1
Wairio	Treatment 1	0	6	1	0
Wairio	Treatment 2	3	3	1	0
Wairio	Treatment 3	3	1	0	1

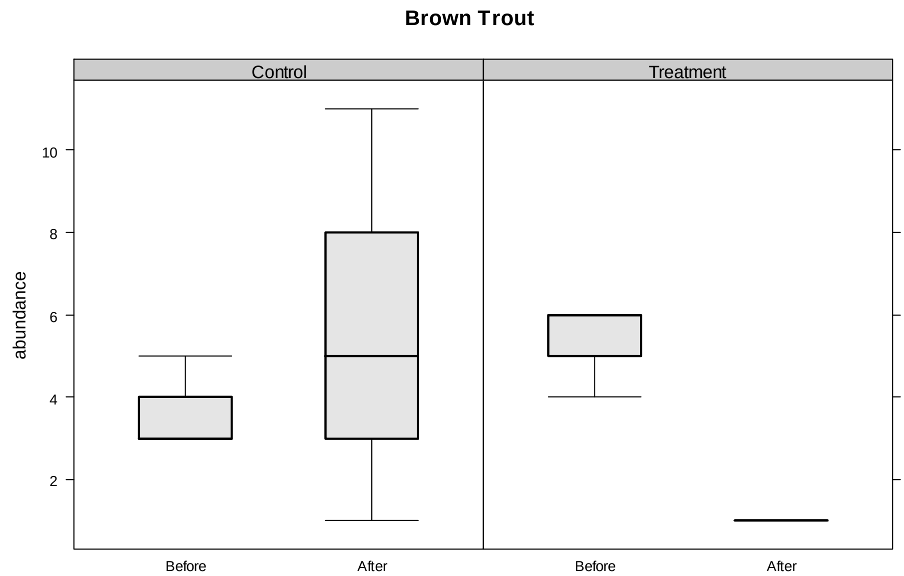

Figure 17. Total abundance of brown trout caught using fyke nets. Box plots have been constructed using 15 m sub-reach data, and summarised by treatment (control/treatment) and timing relative to gravel extraction (before/after).

Brown trout showed a similar increase in length to the electrofishing survey, where the average length across all treatments increased from 141 mm in the pre-impact survey to 201 mm in the follow-up survey (Figure 18). Sampling period was shown to be statistically significant (Dev=0.73, df=1, $p<0.05$), along with treatment type (Dev=0.61, df=1, $p<0.05$), but there was no evidence of any relationship to the drainage maintenance event (Dev=0.01, df=1, $p=0.78$).

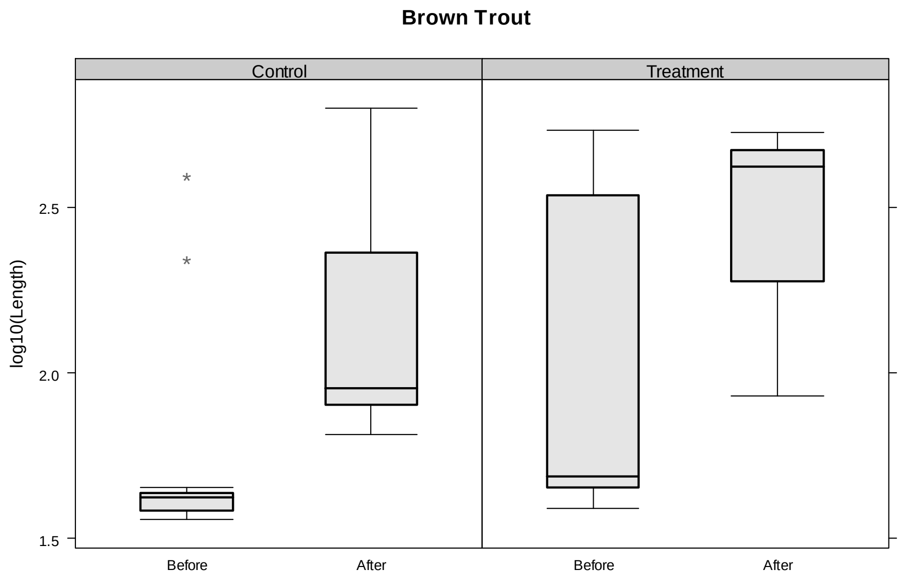

Figure 18. Lengths (mm) of brown trout caught using fyke nets. Data has been summarised by treatment (control/treatment) and timing relative to gravel extraction (before/after). Lengths have been log transformed for display purposes.

Adult Brown Trout Habitat Quality

General Observations

THQI was measured at each of the ten electric fishing, and six fyke netting, sub-sites within each site. The occurrence of high quality adult trout habitat was patchy, with few locations recording adult THQI greater than 0.3 and only one transect having an adult THQI greater than 0.5. Transect observations also indicated available adult trout habitat was patchy, with suitable adult habitat interspersed between long unsuitable reaches. This reflects the presence of long reaches of shallow riffle and run habitat with occasional pools or deeper runs.

Electric Fishing

A significant post-disturbance impact was detected for the adult THQI metric at electric fishing sites (Dev=11.44, df=1, $p<0.001$). The THQI at treatment sites dropped significantly between surveys, but the value remained constant at control sites (Figure 19). Assessment of the habitat data indicated that there was a general reduction in stream depth at the treatment sites, with the percentage of 0 – 0.3 m deep water increasing from 55.4 % to 93.6 %. The THQI is zero for any sites where the water depth is in the range 0-0.3 m deep as this is considered too shallow for adult brown trout. Therefore, the increase in the amount of 0-0.3 m deep water resulted in a THQI of zero for the majority of the treatment sections. At the control sites, on average, 84% of the stream had a depth range of 0-0.3 m in both the before and after assessments. The second major change to the habitat parameters was the near complete removal of in-stream woody material and large items of overhanging cover at all treatment sites. This is probably the result of excavators removing vegetation from the stream channel and stream banks. The combination of depth reduction and loss of in-stream cover are the major causes in the reduction of the adult THQI.

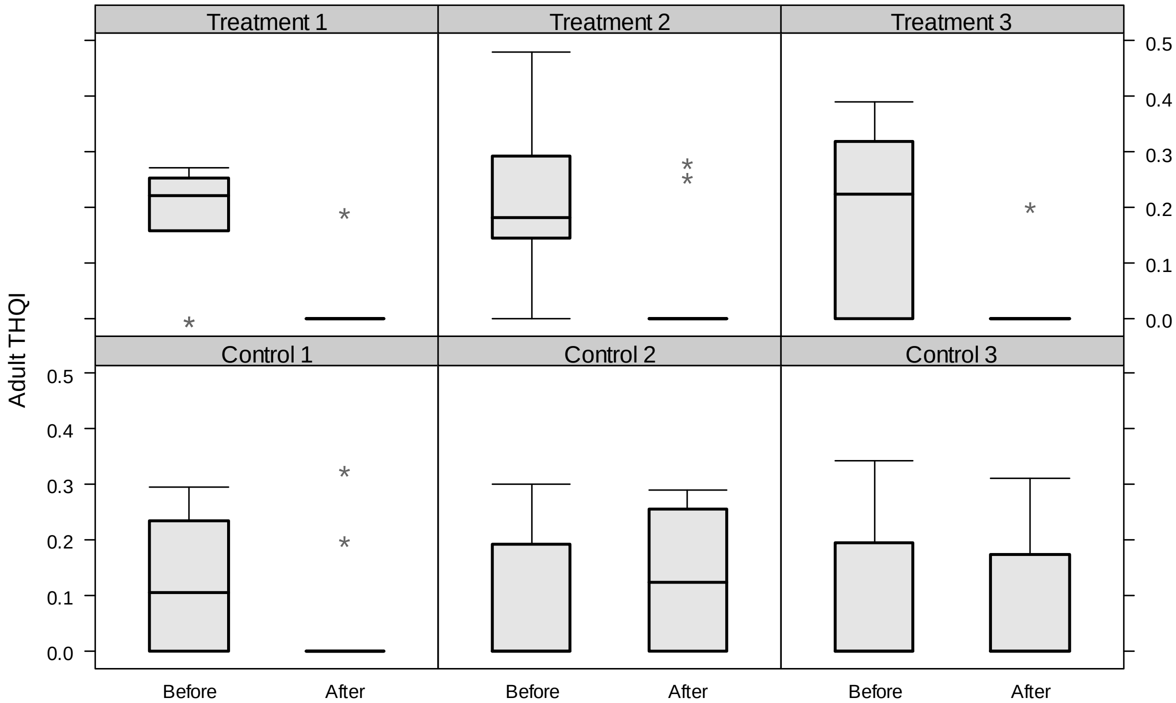

Figure 19. The adult THQI at electric fishing sites. Ten surveys were conducted at each site, each assessing localised habitat over a 25 m sub-reach.

Fyke Netting

Adult THQI scores did not show the same clear response at fyke netting sites (Figure 20), with no evidence of a significant impact found (Dev=0.005, df=1, p=0.15). Overall there was a small decrease in adult THQI score between surveys at treatment sites, but the significance of this interaction was masked by variability at control sites. The stream depth did show an increase in the proportion of shallow water at treatment sites from 71.6% to 82.9%, but there was also an increase in the proportion of shallow water at control sites from 59.2% to 71.3%. Woody debris declined at both control and treatment sites to near zero in the after surveys. Overhanging vegetation also appeared to decline at the treatment sites, but there were relatively low levels of overhead cover at the control sites, so the comparison of before and after abundance of overhanging vegetation was limited by the initial conditions.

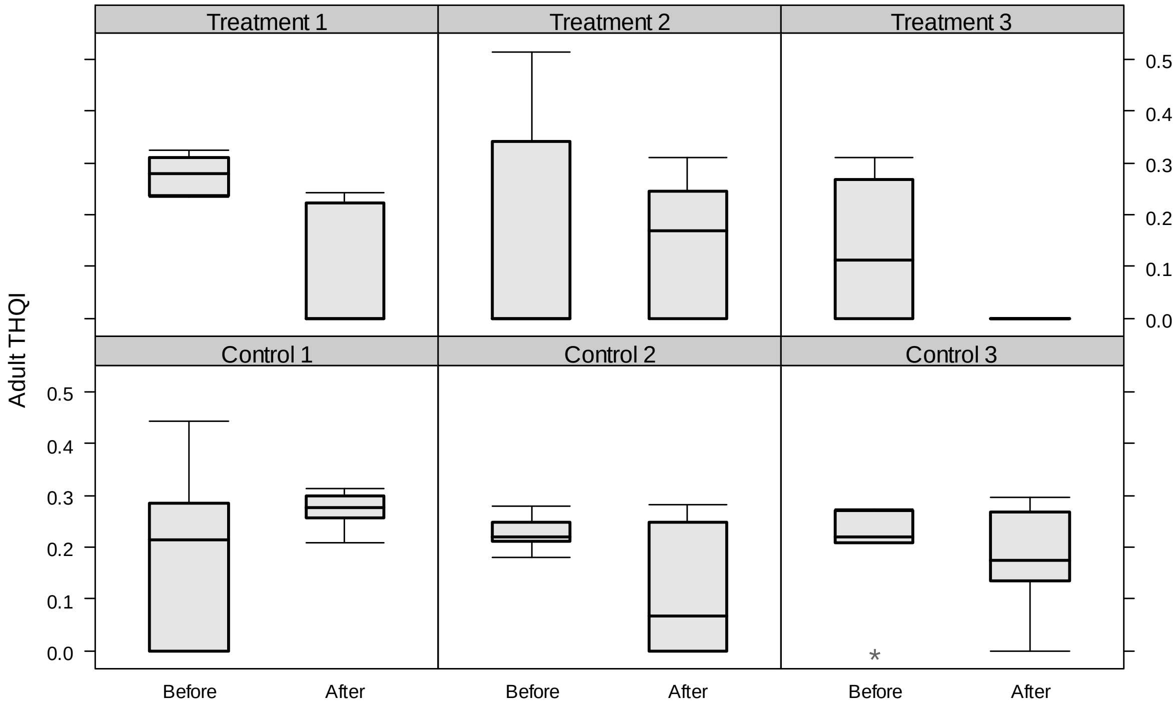

Figure 20. The adult THQI at fyke netting sites. Six surveys were conducted at each site, each assessing localised habitat over a 25 m sub-reach.

Juvenile Brown Trout Habitat Quality

Electric Fishing

The juvenile THQI did not show a significant change between the before and after assessment (Figure 21) (Dev=0.11, df=1, p=0.06), nor was the interaction between treatment and period significant (Dev=0.10, df=1, p=0.08). However, at Treatment Sites 2 and 3 the variance of the juvenile THQI increased post disturbance, with the inclusion of much lower scores. Analysis of THQI metrics suggested that changes at treatment sites were due to the reduction in cover for the trout. Control sites showed very little change in the juvenile THQI at the electric fishing sites.

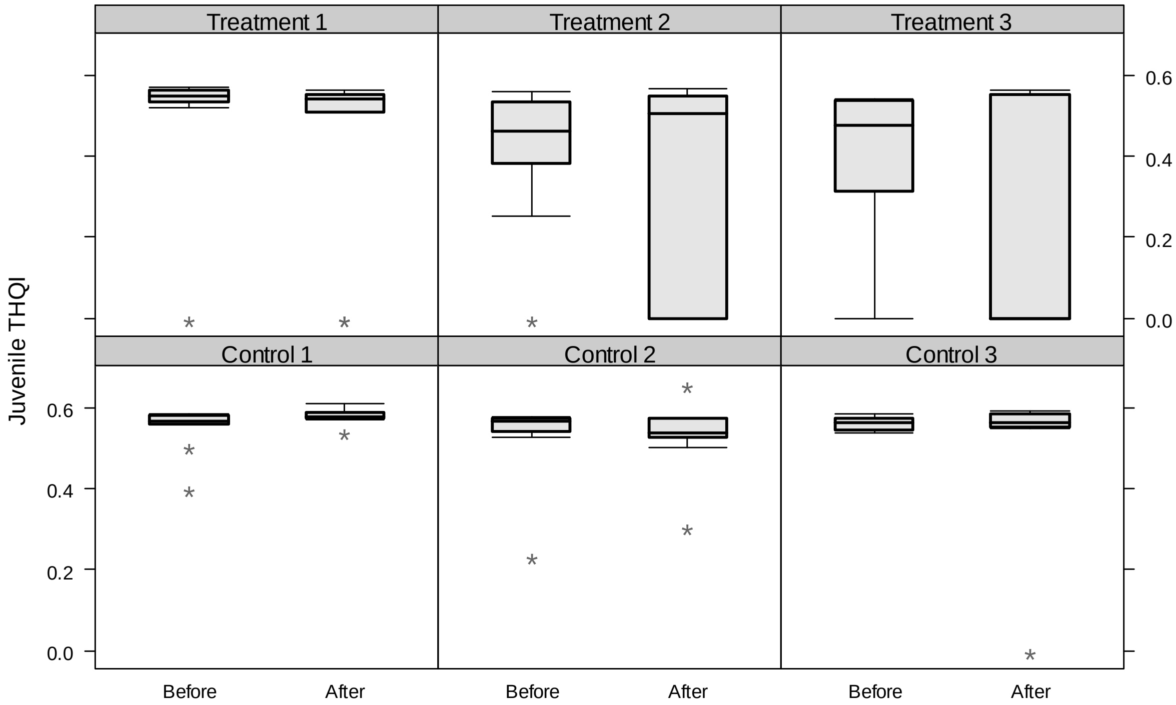

Figure 21. Juvenile brown trout THQI at electric fishing sites. Ten surveys were conducted at each site, each assessing localised habitat over a 25 m sub-reach.

Fyke Netting

At fyke netting sites, juvenile THQI scores showed no significant change between the before and after habitat assessments (Dev = 0.05, df=1, p= 0.22), and no significant interaction between treatment and period (Dev = 0.10, df=1, p=0.10) (Figure 22). However, the three treatment reaches did exhibit different responses to drain clearing disturbance. The juvenile THQI at Treatment site 1 remained essentially the same in the before and after assessments, while Treatment Site 2 had increased post disturbance. Treatment site 3, on the other hand, declined to near zero. These changes can be attributed to the loss of cover to varying degrees at the treatment sites. The control sites showed little change between the before and after surveys.

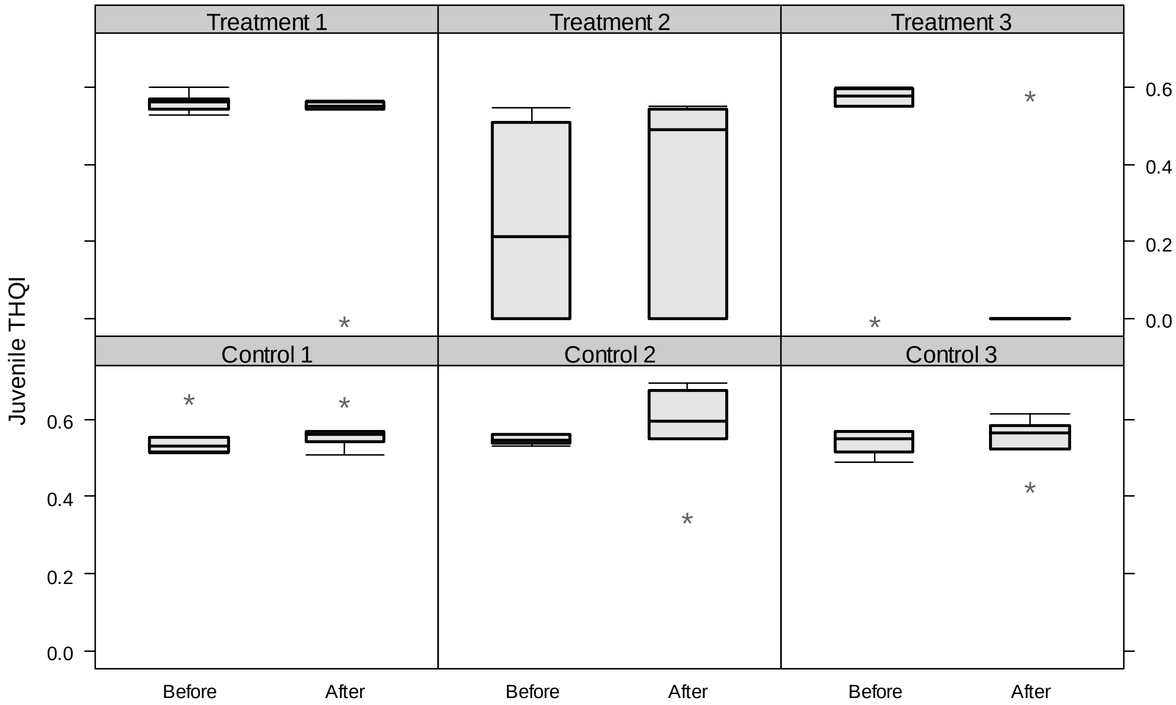

Figure 22. Juvenile brown trout THQI at fyke netting sites. Six surveys were conducted at each site, each assessing localised habitat over a 25 m sub-reach.

Adult THQI vs Juvenile THQI

Figure 23 shows an electric fishing reach before and after re-levelling. Analysis of data from these reaches shows the juvenile and adult THQI were significantly different among all sites (Figure 24) (df=1, F=385.6, p<0.001). Adult habitat was uncommon and of low quality, whereas juvenile habitat was generally common and of relatively good quality. This is reflected in the electric fishing catch, which was dominated by young of the year brown trout.

Figure 23. An equivalent electric fishing reach prior to drainage maintenance (above), and after maintenance (below).

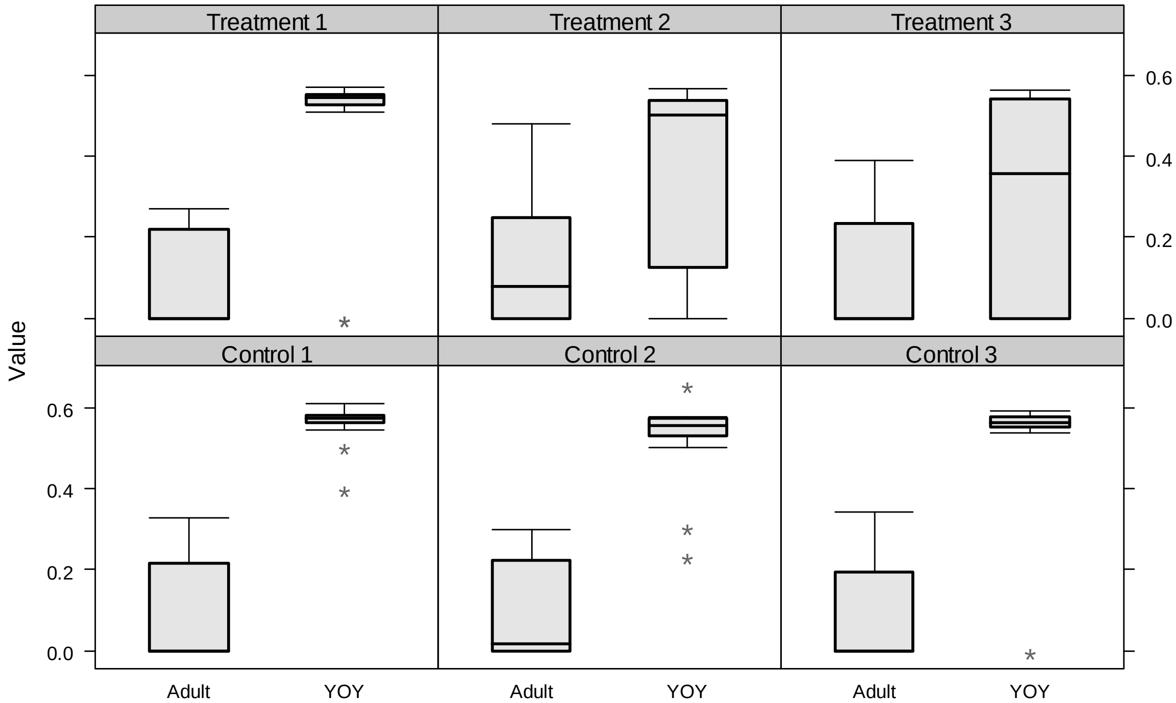

Figure 24. Adult and juvenile THQI scores from the before channel works assessment at the electric fishing sites.

Fyke netting sites also revealed a highly significant difference between the juvenile and adult THQI (df=1, F=122.2, p<0.001), where the juvenile index was much higher at all sites than the adult index (Figure 25). The adult THQI scores indicate that habitat was marginally more abundant at fyke net sites than electric fishing sites, with control sites having very few zero scores for the adult THQI. This indicates that shallow water was less common, and as previously noted fyke net reaches provided more habitat heterogeneity.

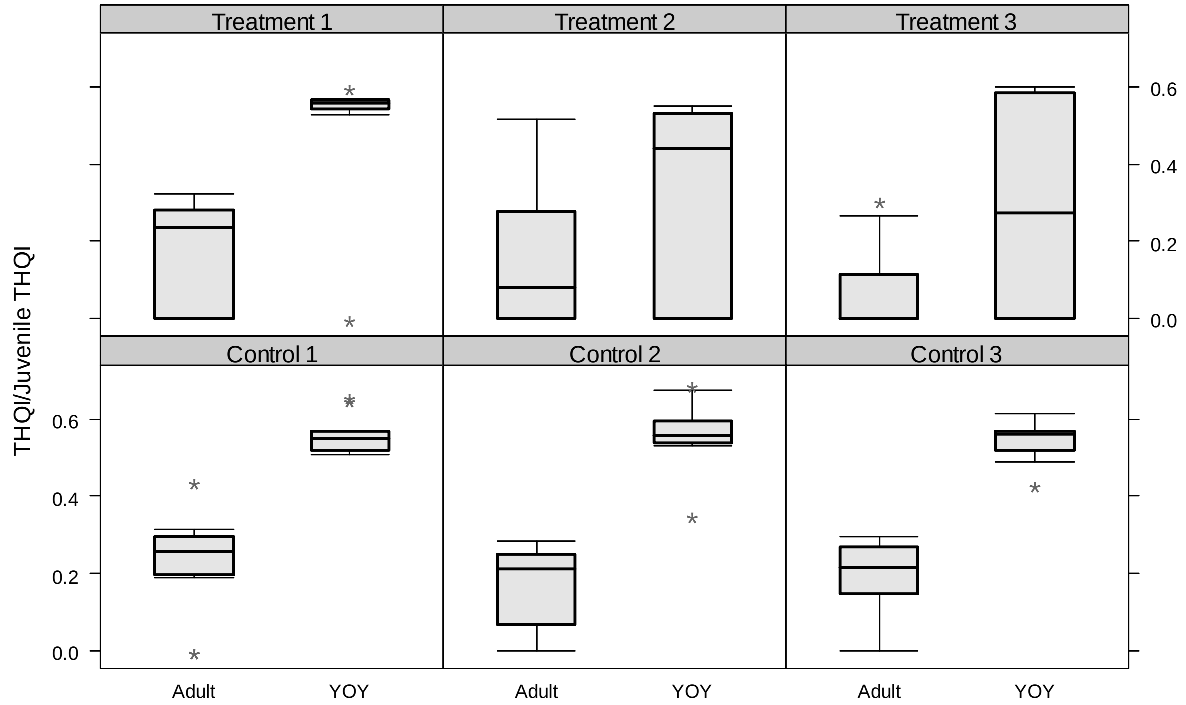

Figure 25. Adult and juvenile THQI scores from the before channel works assessment at the fyke netting sites.

5. Discussion

Abundance

The results of this study illustrate how different survey methods target different subsets of the population, which can have varying responses to community disturbance. There was not enough evidence from electric fishing surveys alone to conclude that the abundance of fish and koura inhabiting the Wairio Stream declined following drain maintenance. However, analysis indicated a significant decline in the captures of brown trout by 82% and longfin eel by 30% in the fyke net surveys at treatment sites following drain maintenance. Despite this, the catch rate for brown trout in the fyke nets was low, and the absolute decline in terms of fish numbers was relatively small. Previous drain clearance monitoring has shown that longfin eels are susceptible to decline during drain clearance either via direct removal or as a result of habitat loss (e.g. Allibone & Dare, 2015), so the observed decline of this species in the Wairio Stream is to be expected.

Pope and Willis (1996) suggest that proper population assessment requires an understanding of seasonal and gear sampling biases. The latter issue was addressed by using two sampling methodologies, electrofishing and fyke netting, which have different efficiencies for different fish communities (Joy et al., 2013). Electrofishing is an active survey method which is particularly suited to capturing species that utilise fast-flowing habitats (e.g. riffles, shallow runs) and works well when cover is limited. Fyke nets, on the other hand, are more selective for cover-seeking mobile species that occupy deeper, slower moving stretches of water (Hubert, 1996). Sampling methods can increase or decrease in efficiency at different rates with regard to habitat change. For example, fyke nets may become more visible in recently cleared habitat and many species may actively avoid them. Electric fishing may be affected by becoming more efficient in the same recently cleared reach, as there is reduced cover for species to shelter in, and stunned fish are more visible to the operator. In this study, drain clearance is likely to have changed the capture rate of fish in both methods; however, the magnitude and vector (i.e. positive or negative) of this change is unknown and shouldn't be assumed.

Seasonal bias is another factor that needs to be taken in to account when assessing aquatic populations, as spawning or migration times can significantly influence the abundance of certain species (Pope & Willis, 1996). This effect was particularly evident in the current study where brown trout and upland bully declined in abundance at both control and treatment sites in the post-impact electric fishing surveys. Brown trout are known to spawn in gravel redds during May and June, and juveniles emerge around September to October (Gibbs, 2007). A large number of juveniles (median length 40-50mm) were captured in the initial survey, especially at Control Site 3, but this number dropped significantly post-impact. The reason for the decline in numbers is unknown; however, there are a number of possibilities including: mortality, migration, habitat preference, and food constraints. Hayes (1995) also found that juvenile brown trout densities were highly variable among sites and years, with no obvious relationship to spawning redd locations. This suggests that the underlying mechanisms are not well understood.

Natural disturbance is a major factor affecting abundance and distribution of periphyton, invertebrates, and fish in aquatic communities (e.g., Biggs 1995). Floods and freshes are the most common form of disturbance event in New Zealand freshwater environments, and studies have shown that flows exceeding three times the median flow (FRE_3) can impact on benthic invertebrates and periphyton (Clausen & Biggs, 1997). With respect to this study, the Southland region experienced a major flood event on the 10 January 2014. This event exceeded the FRE_3 flow at an adjacent flow monitoring site, Otautau Stream (Figure 26), and should be considered an event that may have modified communities and habitat between the before and after surveys. Survey data shows that upland bullies were dominated by small juvenile individuals, which may have easily been dispersed downstream during this event. Upland bullies are batch spawners that lay multiple batches of eggs through the spring and summer (McDowall & Eldon 1997), so the flood disturbance could also have interrupted spawning, reducing juvenile production and recruitment for the following season. Juvenile brown trout are also likely to have been affected. Hayes et al. (2010) found that juvenile brown trout declined significantly in the Rainy River during a 1 in 50 year flood event. For the Wairio and North Head Streams, the flood event in January would have readily displaced some of the juvenile brown trout found in the before survey, which may explain the reduction in numbers at Control Site 3.

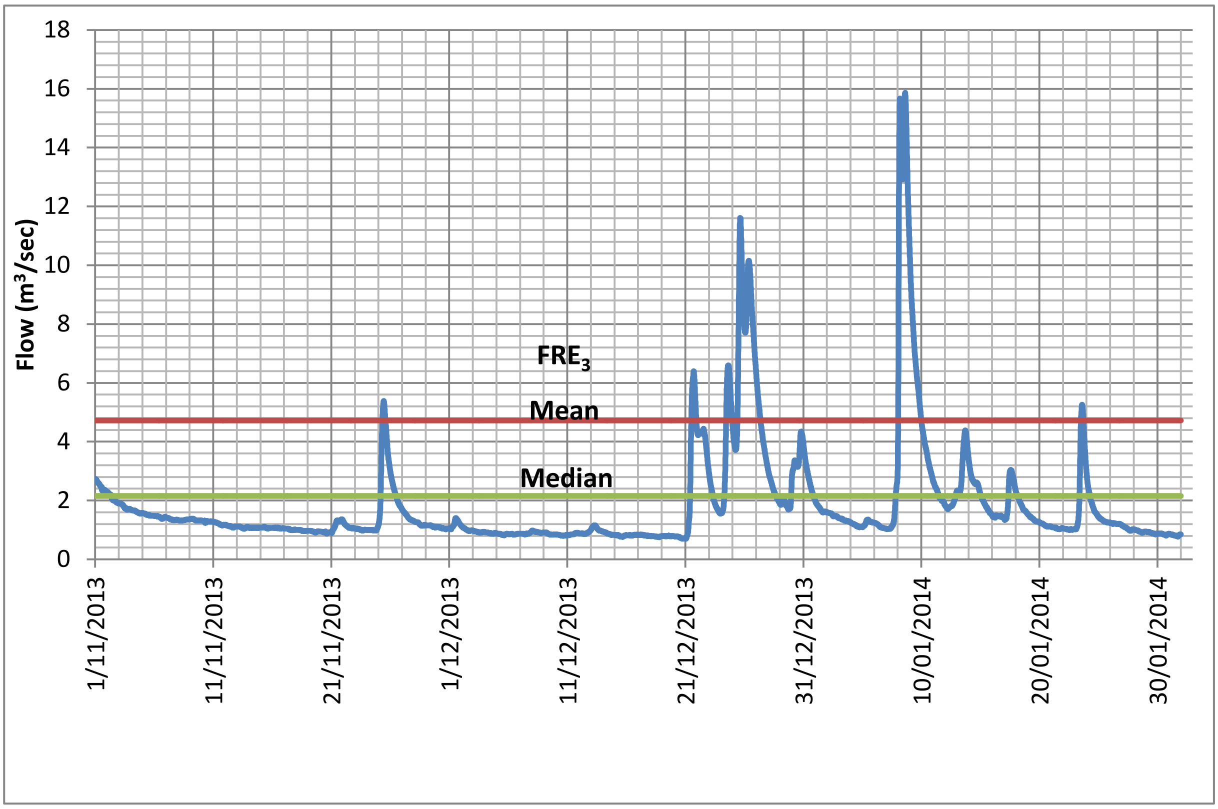

Figure 26. Flow record for Otautau Stream during the study period.

The nature of BACI analysis is to minimise external influences by looking at the interaction between period and impact (see Green, 1979). In order to do this, control and impact reaches must be nearly identical in their external influences throughout time so that the impact signal can be detected. In this case, we have to assume that the January flood impacted upon populations within control sites and impacted sites in the same way, which means that significant interactions for overall fyke netting abundance, which was largely attributed to reductions in brown trout and longfin eel populations, were in fact a result of disturbance from the stream re-levelling process. The flood event may have actually enhanced the ability of this study to detect a difference, due to the fact that fish seek shelter during floods. In this case the control sites should have provided much more shelter than the impact sites, meaning that more individuals were displaced from treatment sites that controls, enhancing the measured difference between the two. However, initial survey results show that the populations present in the Wairio and North Head stream were different, especially with regard to juvenile brown trout abundance. This may have influenced the results by masking any interaction, given that the control and treatment sites are inherently different to begin with. This could possibly explain why there was no detected impact for electric fishing reaches.

Underwood (2002) suggests that variation between control and impact sites is natural, and that study designs must be improved beyond the traditional BACI method to ensure that the impact signal is accurately detected. In this case, a comprehensive survey would involve multiple control streams (e.g. North Head plus two additional streams) and improved temporal replication (e.g. three surveys before impact, and three surveys after). Unfortunately the resources required to complete such a study exceed what is available for a regional council investigation. However, an additional control stream with the same sampling schedule as the current study, in conjunction with an assessment of comparable fish populations via the River Environmental Classification model or New Zealand Freshwater Fish Database, may increase the power of future investigations.

In context of the January flood, it is possible that in-stream works may have provided some benefit to the benthic environment by loosening the stream bed, in particular fine sediment deposits, which would have been subsequently flushed away during elevated flow. Summer et al (1996) described methods for improving trout habitat including spawning habitat that include removal of sediment binding macrophytes, bed disturbance to loosen spawning gravel and fine sediment flushing via water jetting. In the Wairio Stream, macrophytes were removed by mechanical clearance along with a mix of fine and coarser substrate. This was followed by the flood event that would have flushed more fine sediments from the stream as it was no longer bound by macrophyte roots or situated in interstitial spaces. The reduction in fine sediment and loosening of large substrate is likely to improve the overall quality of the stream bed for benthic dwelling fish and invertebrates, provided the removal process has not cut the channel down to bedrock. The substrate data collected as part of the THQI assessment did not note any boulder or bedrock at any transect before or after maintenance, and the streambed at treatment and control sites remained composed of fine sediment, gravel, and cobbles.

Flood events and in-stream works are expected to impact macroinvertebrate communities, displace fish and modify the in-stream habitat. The impact on invertebrate communities has a flow-on effect by potentially reducing food supplies for fish, which can affect overall growth rates. Analysis of juvenile brown trout lengths indicate that these fish continued to grow at comparable rates in treatment and control sites, i.e. there was no treatment period interaction for electric fishing brown trout lengths, which suggests that re-levelling had little impact on juvenile brown trout growth rates. The flood event may have impacted on the growth of juvenile trout, but if so, this occurred evenly across all sites.

Trout Habitat Quality Index (THQI)

The THQI consists of three main components, a water depth parameter, a fish cover parameter and stream bed substrate parameter. To get large changes in the THQI all three parameters are required to change in the same manner –i.e. all increase or all decrease. However, the adult THQI, by Holmes et al., (2012), is designed so that the index value equals zero if the water is 0-0.3 m deep. The reason for this is that regardless of other habitat factors, adult brown trout would be absent if the water was too shallow.

The pre re-levelling THQI shows that the trout habitat in Wairio Stream is largely unsuitable for adult trout due to its shallow depth. This is supported by the low catch of adult brown trout in the electric fishing and fyke net surveys. The post re-levelling THQI showed a reduction in adult THQI at electric fishing reaches, which was generally due to the decrease in water level post disturbance, effectively reducing the THQI to zero. Field observations and photos suggest that fyke net reaches were heterogeneous in terms of the habitat they provided, which could possibly make them more difficult to re-level. However, re-levelling at fyke net Treatment Sites 1 and 3 appeared to be successful, as shallow water had increased to over 90%, as was observed in the electric fishing treatment sites. Fyke net Treatment Site 2, however, appears to be an outlier in the re-levelling process, with more deep water retained after the levelling work; hence this reach had higher scores for the adult THQI. The decline in the adult THQI at treatment sites appears to have had a noticeable effect on large brown trout, as the catch rate declined and it appears these individuals were forced to leave the re-levelled reaches in search of suitable habitat.

The juvenile THQI developed for this report responded differently to in-stream maintenance when compared with the adult THQI. The juvenile THQI used the same habitat data as the adult THQI, so the trends of declining water depth and loss of woody debris cover were the same. However, the higher index scores reflect the preference for juvenile brown trout to inhabit shallow water (Jowett et al., 2006). This increase in the preferred shallow water after maintenance appears to offset the loss of cover that juvenile brown trout use. The post re-levelling habitat assessment also found that cover beneath undercut banks remained available at treatment sites, which would have provided some cover for juvenile brown trout.

Analysis of the juvenile THQI found that there was no significant difference in the THQI between the pre and post disturbance assessments. There was, however, a change in the distribution of scores at treatment sites, which was caused by an increase in the number of low scores at two of the three sites. However, the catch rates of juvenile trout at treatment sites, and their growth rates, appeared to remain relatively constant. This indicates that re-levelling was not sufficient to have noticeable impacts on juvenile brown trout.

With respect to the concern that spawning of brown trout could be negatively affected as a consequence of the re-levelling process, it can be expected that spawning in the re-levelled reaches will decline simply due to the absence of adult brown trout. The two THQI's do not provide information on the quality of spawning habitat, which requires appropriate sized gravels with good sub-surface water flow to provide oxygen to egg deposits. Therefore, it is unknown whether the re-levelled reaches provide suitable spawning habitat. Adult brown trout from the lower reaches of Wairio Stream and the Aparima River may move into the mid and upper reaches of Wairio Stream to spawn, and if the re-levelling has removed fine sediments and created well aerated gravel beds then spawning may still occur. Given the juvenile THQI did not decline, the re-levelled reach is expected to provide good habitat for the juvenile brown trout, even if no spawning actually occurs there.

North Head Stream control sites supported a much larger juvenile brown trout population than the Wairio Stream. This means that any minor habitat loss in the Wairio Stream is likely to have limited impact on the wider trout population, as surplus recruits from other reaches of Wairio Stream, and other streams such as North Head Stream, will continue to maintain the trout population. It is also expected that as channel processes rework the modified section of Wairio Stream, and macrophytes re-establish, factors reducing the THQI and spawning will reduce and the reach will return to it pre-treatment habitat state.

Ecosystem recovery

There is significant potential for the Wairio stream ecosystem to recover following re-levelling disturbance. However this will only occur for large brown trout once channel processes have created new deep water habitats. The development of new pool and deep run habitat will rely on flood events which are large enough to scour the stream bed creating deeper sections, or bed movements that create channel bars that raise upstream water levels. Alternatively, deep water habitat could be artificially created by excavating mid-channel pits during the re-levelling process. THQI scores show that deep water habitat was not common prior to the re-levelling, hence the creation of such habitat would significantly improve the post disturbance adult THQI. However, the longevity of these deep water zones is unknown as they are likely to infill during subsequent flood events. A good understanding of the stream channel and the location of likely scour and deposition sites would be required, so that this information could guide any habitat creation efforts.

The juvenile THQI scores show limited change between the pre and post re-levelling measurements. This indicates that conditions for juvenile trout changed little during the re-levelling process. This is further supported by the uninterrupted growth of juvenile brown trout in Wairio Stream immediately after the re-levelling process. This suggests that fish habitat, and macroinvertebrate prey abundance, remained sufficient to support continued juvenile brown trout growth, and presumably satisfied the requirements of other fish species too.

Summary and Conclusions

The electric fishing and fyke net surveys had different results with regard to the effects of the re-levelling, with the fyke netting data indicating a decline in large brown trout and longfin eels. As the fyke net sites targeted habitat more suitable for large fish, these results provide good evidence of a decline in large fish that previously inhabited the re-levelling reach.

The use of the two fishing methods demonstrates the importance of using multiple methods when assessing fish communities. This allowed the effective sampling of different habitats and different size classes of fish providing a broader assessment of potential effects.

The adult THQI showed a significant decline due to reduction in water depth during re-levelling. This will have had a substantial effect on the numbers of adult brown trout using the re-levelled reach. This effect is somewhat limited by the lack of good adult trout habitat prior to re-levelling. The recovery of adult habitat will require the creation of deep water habitat, which will either occur gradually with time, or can be artificially created during the maintenance process.

The juvenile THQI showed no significant differences between the pre and post re-levelling surveys, although a reduction in fish cover did increase the occurrence of low quality juvenile habitat in the treatment reaches. However, juvenile brown trout present in treatment reaches continued to grow at the same rates as juvenile brown trout in the control reaches, indicating that any reduction in habitat quality was not having a noticeable effect.

With regard to the original intention of study, there is likely to be a reduction in spawning in the re-levelled reaches due to a decline in the number of resident adult brown trout, and the lack of deep water habitat. The quality of the spawning gravels in the re-levelled reaches was not directly assessed, and while certainly disturbed by the re-levelling process, this may have assisted flushing fine sediments from the stream bed. However, the re-levelling disturbance occurred in late November and the stream could be expected to have stabilised by the trout spawning period in late May and June the following year. This suggests that direct disturbance of spawning is unlikely to have occurred.

Recommendations

A key aspect of this study was the decline in the occurrence of adult brown trout habitat that was due to a reduction in water depth. For further re-levelling projects it is recommended that some effort is made to create some areas of deep water habitat (greater than 30 cm deep). This will benefit brown trout and other large fish such as longfin eels. The objective of a re-levelling project is to lower the bed of the stream as opposed to a drain maintenance project that seeks to improve water flow. Therefore, a re-levelling project could also consider the placement of some large woody material (e.g. tree trunks or stumps) at a few sites in the project reach to increase habitat diversity and to create scour zones and riffles that may maintain clean gravels for spawning. Future studies should also consider the use of multiple control streams and enhanced temporal replication.

Acknowledgements

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Appendix 1: Cross Sectional Surveys

Cross Sections

The following section provides the results of the cross sectional surveys that were performed that the upper and lower reach of each survey site. This part of the study encountered a number of difficulties such as: landowners moving fence posts that were used as benchmarks, cross sections that did not follow the same perpendicular path in both surveys (before and after), loss of data sheets, and measurement errors made by field staff. As a result, these cross sections are considered to be inaccurate and have been included in the appendix for sake of completeness only.

Figure 27 and Figure 28 depict cross sections for each electric fishing site. We would generally expect control sites to remain constant between surveys, while treatment sites would show a more excavated profile in the post impact survey. Most of the profiles for electric fishing sites show this trend, with the exception of the top and bottom profile for control site 3. The profiles for this site appear identical in shape but offset in vertical distance, which may indicate a field measurement error. The top and bottom profiles of Treatment Site 1, and the bottom profile of Treatment Site 3, are also missing which significantly reduces the value of this dataset.

Figure 29 and Figure 30 show the cross sectional profiles for fyke net surveys. Control Site 3 shows a vertical offset that is comparable to the vertical offset for Control Site 3 of the electric fishing surveys. These two sites are physically close to each other and are likely to have been surveyed by the same field team, which provides more evidence that the vertical offset is an artefact of measurement error. If this assumption is true, and we also assume that the before-after profiles for Control Site 3 are identical, then we can see that treatment sites show significant signs of channel excavation in comparison to the control sites. However, given the uncertainty that has arisen with measurement accuracy, it is difficult to draw any solid conclusions.

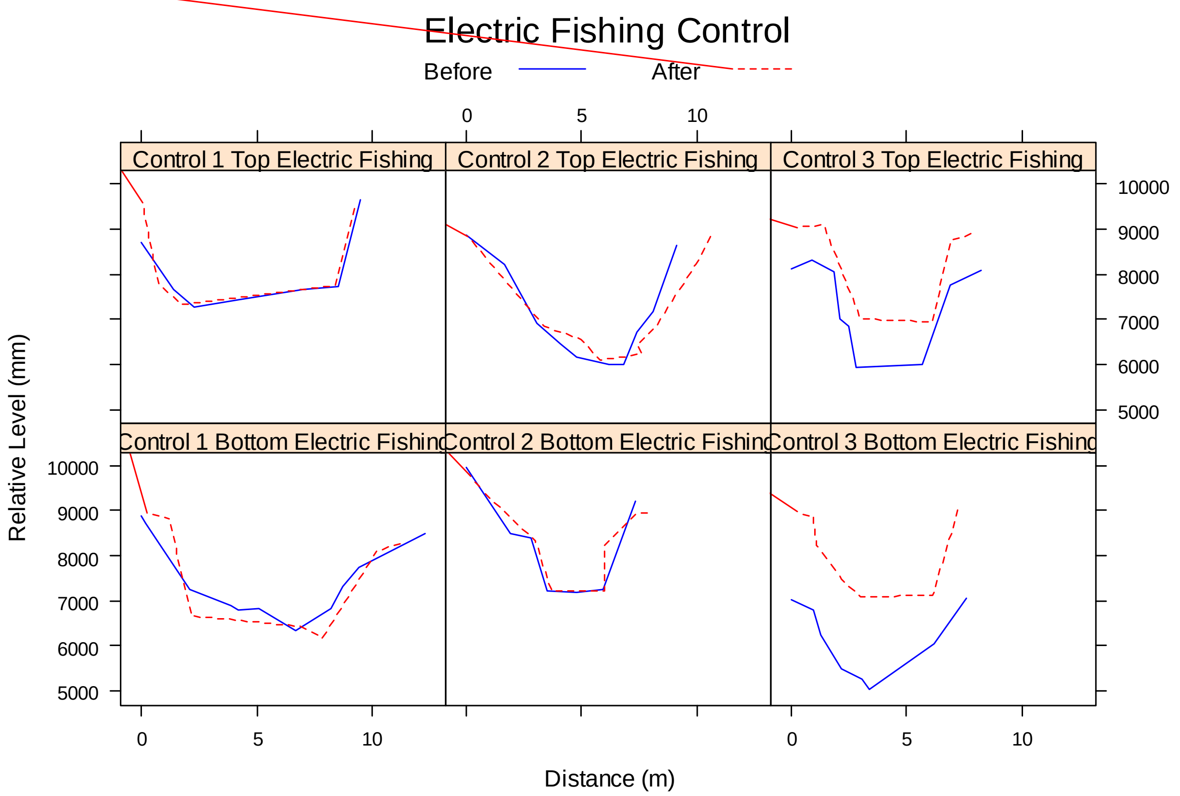


Figure 27. Cross section profiles for electric fishing control sites. The solid line represents the pre-impact survey, and the broken line represents the post-impact survey.

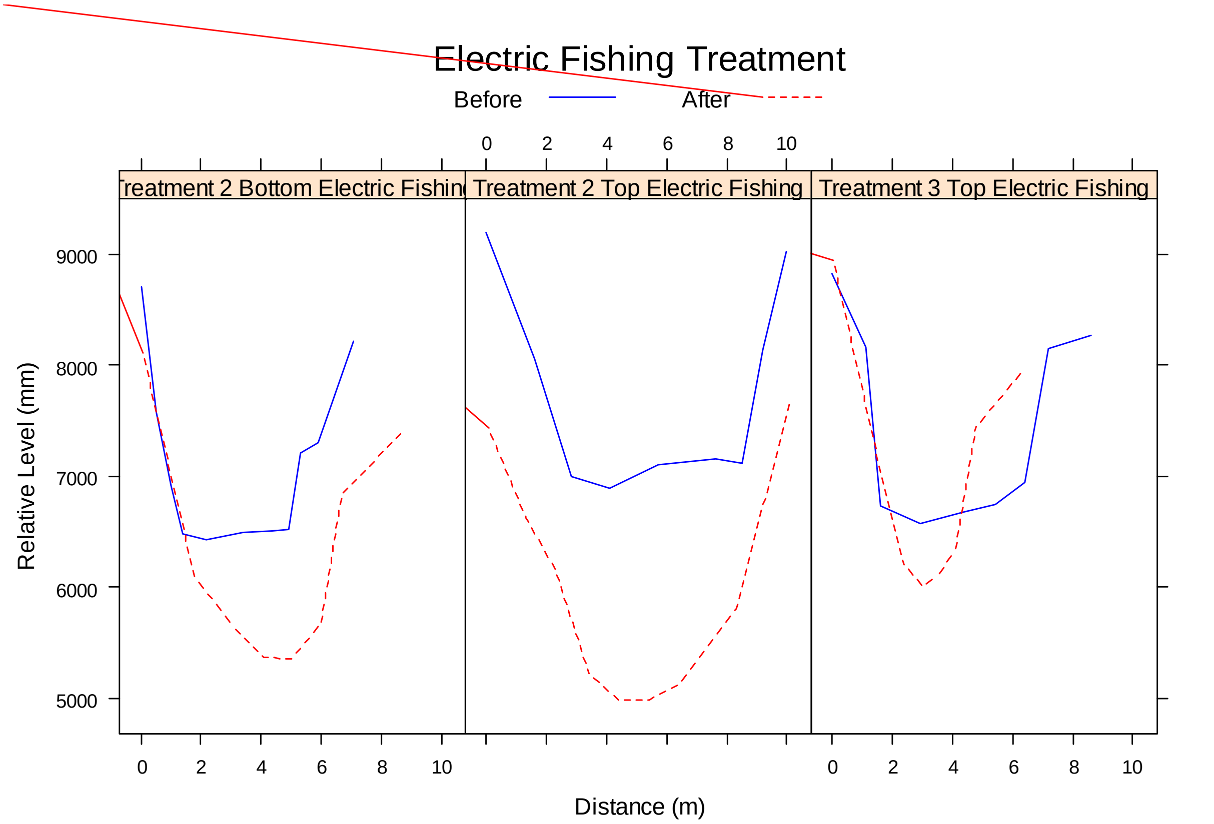


Figure 28. Cross section profiles for electric fishing treatment sites. Note that three sets of profiles are missing from this dataset. The solid line represents the pre-impact survey, and the broken line represents the post-impact survey.

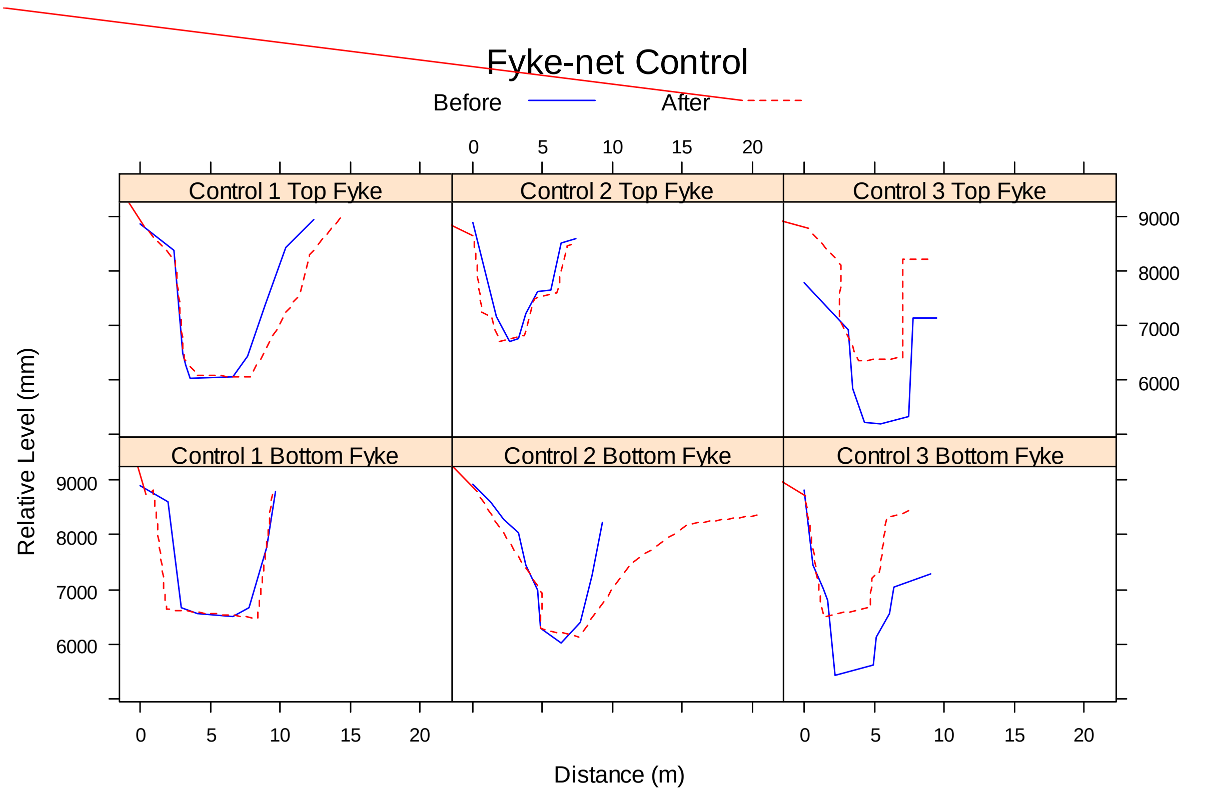


Figure 29. Cross section profiles for fyke netting control sites. The solid line represents the pre-impact survey, and the broken line represents the post-impact survey.

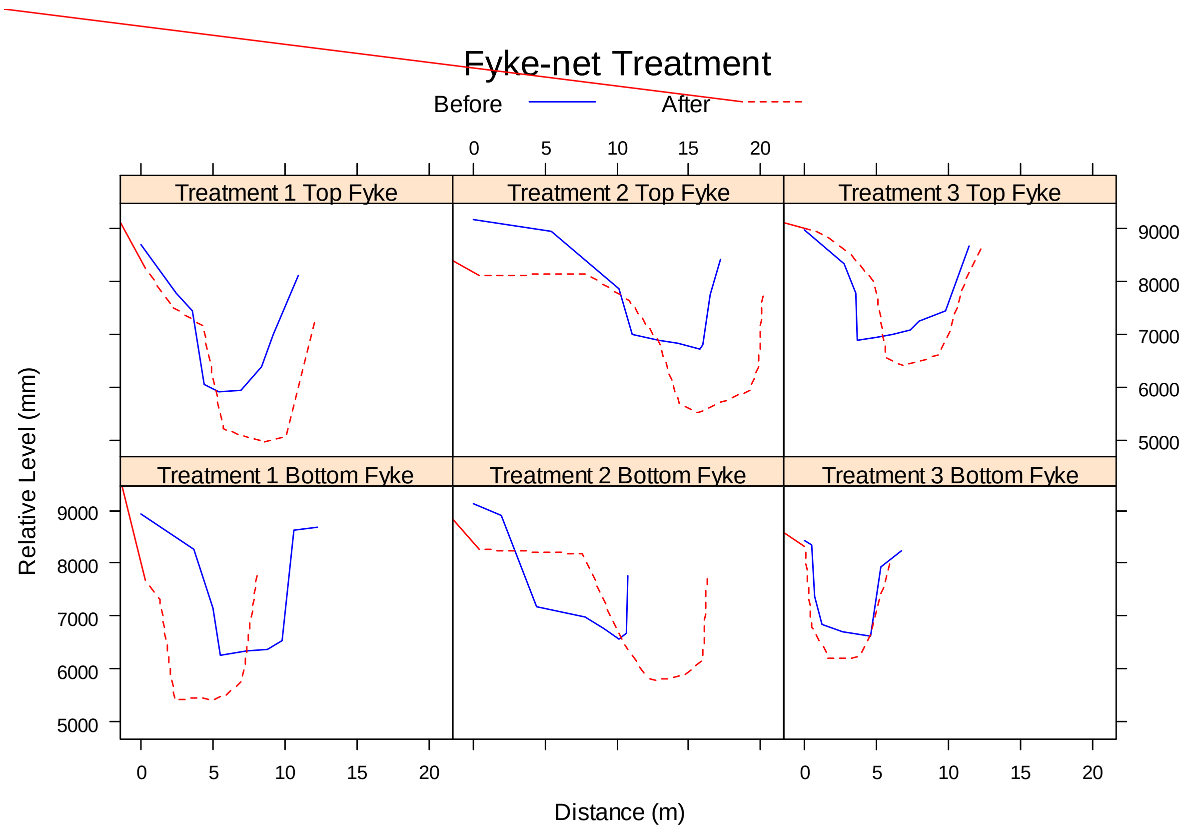
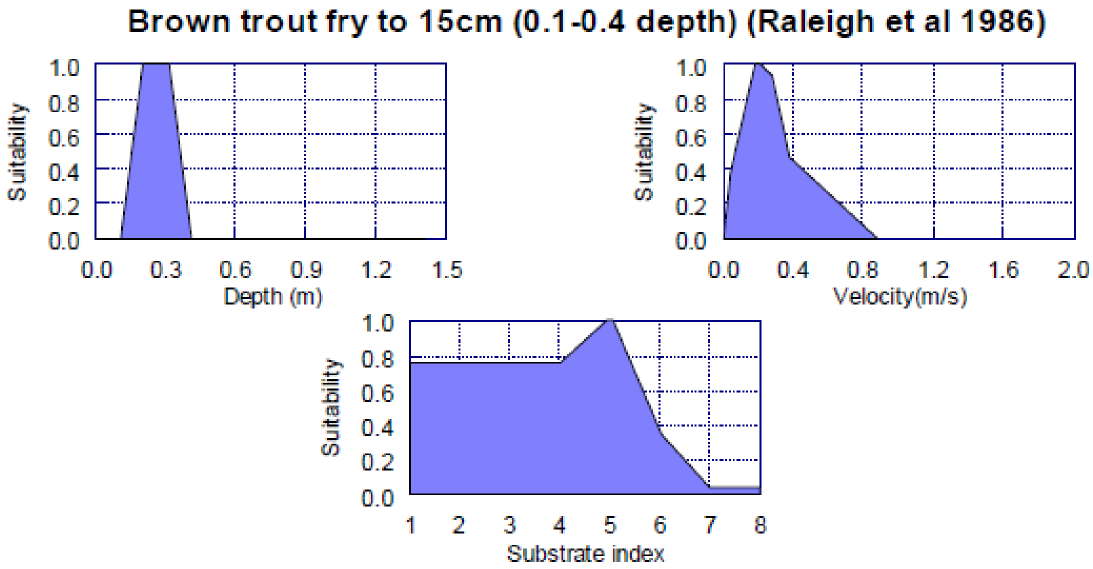


Figure 30. Cross section profiles for fyke netting treatment sites. The solid line represents the pre-impact survey, and the broken line represents the post-impact survey.

Appendix 2: THQI Assessment Data Sheet

<table>
<tr><td colspan="2">Stream:
Reach: 1 (dwnstm)</td><td colspan="2">GPS:
E
N</td><td colspan="2">Date:</td><td colspan="2">Assessor team:</td></tr>
<tr><td colspan="8">% Mesohabitat types:</td></tr>
<tr><td colspan="2">Riffle</td><td colspan="2">Slow run</td><td colspan="2">Fast run</td><td colspan="2">Pool</td></tr>
<tr><td colspan="8">%Depths:</td></tr>
<tr><td colspan="2">0 – 0.3 m deep</td><td colspan="2">0.3 – 0.5 m deep</td><td colspan="2">0.5 – 1 m deep</td><td colspan="2">1 m + deep</td></tr>
<tr><td colspan="8">%Sediment cover:</td></tr>
<tr><td>Fine sed (<2mm)</td><td>Gravel (2 – 30mm)</td><td>Coarse gravel (30-63mm)</td><td colspan="2">Small cobble (64-160mm)</td><td>Large cobble (160-255mm)</td><td>Boulder (>256mm)</td><td>Bed rock (continuous)</td></tr>
<tr><td colspan="8">Shuffle test score (1-4 scale):
(in run or pool-tail (glide) only)</td></tr>
<tr><td colspan="4">% Weed/macrophyte cover</td><td colspan="4">% Algal cover (include only filamentous or thick algal mat cover >3mm)</td></tr>
<tr><td colspan="8">Fish cover</td></tr>
<tr><td colspan="8">Undercut bank (linear m of bank edge length)</td></tr>
<tr><td colspan="2">0 – 0.3 m deep</td><td colspan="2">0.3 – 0.5 m deep</td><td colspan="2">0.5 – 1 m deep</td><td colspan="2">1 m + deep</td></tr>
<tr><td colspan="8">Overhanging veg (linear m of bank edge, include only if obscuring stream bed from view)</td></tr>
<tr><td colspan="2">0 – 0.3 m</td><td colspan="2">0.3 – 0.5 m</td><td colspan="2">0.5 – 1 m</td><td colspan="2">1 m +</td></tr>
<tr><td colspan="2">Woody debris (m^2) (include items >1m*0.3m)</td><td colspan="2">Submerged branches (m^2) include items (>1m*0.3m)</td><td colspan="2">Turbulence (m^2) (Include if the stream bed is obscured and depth is >0.3m.)</td><td colspan="2">Manmade cover (m^2) (e.g. rip-rap, bridges, old tires)</td></tr>
<tr><td colspan="8">Velocity at fasted point in 20 m sub-reach - tennis ball test over 3m length</td></tr>
<tr><td colspan="3">Run one (seconds)</td><td colspan="2">Run two (seconds)</td><td colspan="3">Run three (seconds)</td></tr>
<tr><td colspan="7">Fish Species ID</td><td rowspan="5">Photo taken?</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td colspan="7"></td></tr>
<tr><td colspan="7"></td></tr>
<tr><td colspan="7"></td></tr>
</table>

Appendix 3: Habitat preferences from Jowett et al (2006)



Appendix 4: Site photographs

Pre streambed re-levelling:

Treatment Sites

Photo 1: An example of a typical electric fishing reach prior to re-levelling.

Photo 2: An example of a typical fyke net reach prior to re-levelling.

Photo 3: Broom covered banks in fyke net treatment sites prior to re-levelling. Note the shade line on the right side of the photo.

Control Sites

Photo 4: Electric fishing control site 1, upstream of re-levelling on the Wairio Stream. This reach had a number of large conifers shading the stream on the true right bank.

Photo 5: Fyke net control site 1. This site had similar shading properties, and was located just upstream from electric fishing control site 1.

Photo 6: A typical electric fishing reach on the North Head Stream. This stream was deeply incised and had an abundance of shading vegetation.


Photo 7: Areas of riffle and run on the North Head Stream.


Photo 8: In stream obstacles such as fallen branches, had created areas of heterogeneous habitat in the North Head Stream.

Photo 9: An example of a deep run (left side of photo) on the North Head Stream.

Post streambed re-levelling:

Treatment Sites

Photo 10: An excavated tile drain outflow pipe, post re-levelling. This drain would not have been operating prior to re-levelling.

Photo 11: An example of habitat homogeneity resulting from re-levelling. Gravel bars and meanders were removed as part of the process leaving a straight and featureless channel.

Photo 12: Another example of homogenous, post re-levelling habitat. Note the rapid, shallow flow on the outer bend. Exposed tile drain outflows can be seen on the left side of the picture.

Photo 13: View from true left bank looking downstream towards the Longwoods forest. All large vegetation was removed as part of the re-levelling process.

Photo 14: Another typical post re-levelled electric fishing stretch, devoid of significant shading vegetation.

Control Sites

Photo 15: Zane and Stu electric fishing control site 1 post re-levelling.

Photo 16: Stu setting up a fyke net at control site 1, post re-levelling.

Photo 17: Stu carrying out the habitat survey on a North Head Stream control site. Note the white tile in the centre of the picture that was used for the shuffle test; a metric of fine sediment deposition.

Photo 18: Stu carrying the electric fishing specimen bag after fishing a reach on the North Head Stream.

Photo 19: A Fyke net deployed on the North Head Stream.

Photo 20: A large, 1.5m deep pool on the North Head Stream.

Miscellaneous Photos:

Photo 21: Suspended sediment entering the Otautau Stream while the digger was active on the Wairio.

Photo 22: A medium sized longfin eel (*Anguilla dieffenbachii*) from one of the Wairio treatment electric fishing sites.

Photo 23: Highly reduced water coming from a tile drain on the Wairio Stream.

Photo 24: Perch (*Perca fluviatilis*) caught in one of the fyke nets. This species is usually found in more coastal riverine reaches, although they have been recorded further inland in areas of Southland, Otago, and Canterbury (https://tad.niwa.co.nz/atlas/image/192499).

Photo 25: The North Head seemed to be accumulating old fertiliser bags and other farm rubbish. It is unknown where this was coming from**.**

Photo 26: A large koura caught on the Wairio Stream. This is one of the larger specimens seen by either Fish and Game or Environment Southland staff.